Engineering for Growth:
Assessing the Đề Gi Port and Storm Shelter System for Development

CEGM3000: Multidisciplinary Project

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For a multidisciplinary project as part of the master curriculum Civil Engineering at the TU Delft, an assessment is carried out concerning the Đề Gi Port and Storm Shelter system in the Bình Định province, Vietnam, with a particular emphasis on planned expansion and its implications for nautical accessibility and network capacity.

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November 3, 2023

Preface

The research project is the result of our collective efforts as a group of students studying the Civil Engineering Master at the TU Delft. We came together with a shared interest in doing a multidisciplinary project and ended up studying the Đề Gi storm shelter upgrade in Vietnam. Our experiences in this foreign setting shaped our approach and broadened our perspectives.

Throughout this project, we faced challenges and worked together to find solutions which is very valuable to us in our development.

This research project represents our collaborative work and the knowledge we gained. We hope it contributes meaningfully to the academic discussion regarding the Đề Gi area.

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Hà Nội, November 2023

Acknowledgement

The project team wishes to express their appreciation to the following individuals and institutions for their valuable support throughout the course of this research project:

Thủy Lợi University, Hanoi, Vietnam: The project team is thankful to Thuy Loi University for the hosting opportunity of this research and for providing access to the essential data used in the study. It played a key role in the completion of the project. The project team has had an adventurous and meaningful learning experience.

Mr. Trung and Mr. Hải, Supervisors at Thủy Lợi University: The guidance and expertise of Mr. Lê Hải Trung and Mr. Le Hai were useful in shaping the research. Their hospitality and mentorship contributed to the project's quality and success, and to the team's integration at the University.

Delft University of Technology (TU Delft): The opportunity to undertake a multidisciplinary project abroad at TU Delft enhanced the project team's learning experience on academic, team collaborative and personal levels. Also, the change for a cultural experience in the form of an international project contributed to the group's knowledge.

Mr. Binsbergen and Mr. Công, Supervisors at TU Delft: The project team is appreciative of the guidance and mentorship provided by Mr. Binsbergen and Mr. Công from TU Delft.

Fast Fund and TU Delft Global Initiative Fund: The financial support by Fast Fund and TU Delft Global Initiative Fund greatly supported the research project. The project team acknowledges their contribution with profound gratitude.

Ministry of Agriculture and Rural Development of Vietnam: parts of the data used in this study is provided by the research project "Study on applying sand bypassing system and preventing depositing for estuaries along the Central Coast of Vietnam" funded by Ministry of Agriculture and Rural Development of Vietnam.

The collaborative effort, with the institutions and individuals mentioned above, was received with much gratitude by the project team.

Abstract

In Vietnam, the fishery sector is vital for the economy. The government strives towards an increase in fishing activities in the coming years. The Quy Nhơn port, a key hub in central Vietnam, is set to accommodate more international vessels. This means local fishermen must rely on other ports like Đề Gi, which also needs upgrading to meet aquaculture production goals. To support the fishing sector's growth in Bình Định province, the Khu neo đậu đầm Đề Gi (KND) project is initiated by the local authorities and will contribute to upgrading the Đề Gi port and construct a new storm shelter. However, this project has potential issues: (1) it focuses mainly on storm shelter capacity and does not address the increase of traffic in the current network capacity, (2) the estuary suffers from sedimentation issues, limiting the nautical accessibility of the access channel, resulting in a decrease of port and storm shelter functionality. To tackle these problems the following main question is investigated:

What is the current performance of the Đề Gi port and storm shelter system, and how can engineering methods be used to assess its potential for future growth within the broader context of sustainable socio-economic development?

The main research question is going to be supported by the following sub-questions:

- *How will the current logistic service network perform in the future vision as foreseen by the responsible authorities and how to verify it with an engineering responsible approach?*
- *How to examine the accessibility of the port and storm shelter in the KND project, while ensuring a safe, robust, durable and effective system?*
- *What are the consequences of the port and storm shelter upgrade on the logistical system and on the conditions in the waterway and what impact does this have on the Đề Gi area?*

The main aim of this research is *'apply engineering methods to understand the system in order to assess its performance and put this in the context of the socio-economic development of the Đề Gi area and the Bình Định province.'* To achieve this, various research methods are used to analyse the current state of logistic service and nautical accessibility, to identify the bottlenecks in the systems. To include the aspect of incorporating the socio-economics in a broader context of the area, a stakeholder analysis is introduced. For the inland logistic services of the port, a qualitative 4(+1)-transport modelling model is established. For investigating the nautical accessibility, a comprehensive system analysis, including the topics of (1) climate, (2) hydrodynamics, (3) morphodynamics and (4) current and future conditions of the access channel, is conducted to provide insights into nautical accessibility challenges to enhance the safety, robustness, durable and effectiveness of the access channel.

To analyse the logistic service system in the area, field observation in combination with interviews are performed to have a concrete insight into the characteristic harbour patterns, traffic and transportation system and the current transportation network for the goods originating from the harbour. Additionally, various development plans and visions outlined by local authorities are reviewed to gain a comprehensive understanding of the area's future development. By evaluating the current state of the logistic service network alongside the region's development plans, the limitations within the network are identified. The primary bottlenecks in the logistic services system predominantly revolve around capacity and quality issues in the existing road network. Many of these limitations are expected to be addressed through the implementation of the local authorities' development visions. However, for a reliable conclusion, an engineering approach is necessary. To achieve this, a 4(+1)-step transport modelling, coupled with an All-Or-Nothing traffic assignment, is recommended. For the examination of the Đề Gi road network and traffic assignment, this

approach provided an initial assessment of the intensity of each link within the study area relative to its corresponding capacity.

The second sub-question is addressed through an analysis and depth assessment, uncovering critical nautical accessibility bottlenecks. These include draught limitations and climate change impacts, potentially compromising safety, robustness, durability, and effectiveness. A depth assessment, considering different vessel types and water levels, provides insights into the current channel status. Safety is a major concern, especially for larger vessels during low water conditions, heightened by climate change. Robustness faces challenges due to sedimentation and storm vulnerabilities. Durability is threatened by changing climate conditions affecting sediment dynamics and storms. Effectiveness remains relatively stable, with 90% accessibility for the expected future vessel fleet. These findings particularly point to the need for safety and durability measures, especially in light of future climate change predictions, necessitating climate-resilient design.

The third sub-question explores the port and storm shelter upgrade's impact on Đề Gi. Consequences include increased traffic and vessel intensity, on land and through the access channel, and a shift in vessel fleet mix, requiring improved infrastructure and access channel design. This enhances safety and, ultimately, drives socio-economic growth, education, and investment appeal in the Đề Gi area.

In the Đề Gi area, current transportation capacity falls short of future growth needs. Local authorities' development plans aim to resolve logistic service bottlenecks. Nautical accessibility is currently 90% effective but not consistently safe. Climate change threatens its durability. Engineering models, like the 4(+1) step methodology and comprehensive system analysis in combination with a depth assessment, uncover transport and nautical accessibility challenges. These methods assess future impacts of the port and storm shelter upgrade, benefiting the Đề Gi area with socio-economic development, improved safety and new opportunities for the local community.

Contents

List of Abbreviations

AON .... All-or-nothing
ASC .... Alternative Specific Constant
ASEAN .... Association of Southeast Asian Nations
AWACS .... Airborne Warning and Control System
BTA .... Bilateral Trade Agreement
CD .... Chart Datum (Hon Dau elevation system in Vietnam)
CT01 .... North-South Motorway Vietnam
CV .... Chevaux-Vapeur
D .... Minority/local road
DT .... Provincial Road
DWT .... Deadweight tonnage
GDP .... Gross Domestic Product
GIS .... Geographic Information System
HW .... High water
IPCC .... Intergovernmental Panel on Climate Change
KND project ... Khu neo đậu tránh trú bão đầm Đề Gi
LW .... Low water
MARD .... Ministry of Agriculture and Rural Development
MHW .... Mean high water
MLW .... Mean low water
MSL .... Mean sea level
MW .... Mean sea level
NE monsoon ... North East Monsoon
OD-pair .... Origin destination pair
PCU .... Passenger Car Unit
QL .... National highway
SW monsoon ... South West monsoon
TPP .... TPP Trans-Pacific Partnership
UKC .... Under-Keel Clearance
UN .... United Nations
US .... United States
VND .... Vietnamese Dong

List of Definitions

Accessibility	The quality of being able to be entered.
Bathymetry	The measurement of the depth of water in oceans, seas or lakes.
Bottlenecks	Any situation where something is delayed, i.e. traffic.
Centroid	Point that identifies as the centre of activity within a zone and connects that zone to the transportation network.
Connectivity	The state or extent of being connected or interconnected.
Delta	Wetlands that form as rivers empty their water and sediment into another body of water.
Diurnal	Daily; Of each day; ”Diurnal rhythms”. Often used in combination with tide, meaning: Diurnal tidal cycle experiences one high and one low tide every lunar day.
Draught	Ship’s hull vertical distance between the waterline and the bottom of the hull (keel).
Durability	Refers to being able to last a long time without becoming damaged.
East Sea	Biển Đông also known as South China Sea.
Effectiveness	Refers to the ability to be successful and produce the intended results.
Estuary	A partially enclosed, coastal water body.
Fresh Water Lagoon	Vịnh Nước Ngọt, name of the lagoon the near the Đề Gi estuary.
Hydrodynamics	Branch of physics that deals with the motion of fluids and the forces acting on solid bodies immersed in fluids.
Lagoon	A shallow body of water protected from a larger body of water (usually the ocean) by sandbars, barrier islands or coral reefs. Also referred to as Estuary.
Link	An arc that allows flow through it, as in a road link.
Lunar day	The interval of time between two successive crossings of the meridian by the moon (roughly 24 hours and 50 minutes).
Monsoon	A seasonal change in the direction of the prevailing, or strongest, winds of a region.
Morphodynamics	Study of the interaction and adjustment of the seafloor topography and fluid hydrodynamic processes.
Morphology	Study of the shape and structure of coastal systems or subsystems. E.g. the morphology of a bedform.
Node	A point of connection in the network.
Peninsula	A piece of land almost surrounded by water or projecting out into a body of water.
Road capacity	The maximum traffic flow obtainable on a given roadway.

Road intensity	The number of vehicles passing on a particular section of the road at a specific time.
Robustness	Refers to a situation in which the system is strong and unlikely to fail.
Safety	A place where individuals are secure and not in danger or at risk.
Sedimentation	The process of settling or being deposited as sediment.
Supply chain	The sequence of processes involved in the production and distribution of a commodity.
T-jetty	A jetty shaped in the form of a T.
Traffic	Refers to the movement of vehicles, goods, or people on a (road)network.
Transport	Refers to the means of moving people and goods.
Transshipment	The shipment of goods to an intermediate destination, then to another destination.

List of Tables

List of Figures

1 Introduction

The fishery sector is a vital economic sector in Vietnam. Various master plans aim to boost its growth. The key port of Quy Nhơn, central Vietnam, is set to accommodate more international vessels. This means that local fishermen must rely on other ports like Đề Gi. To support the fishing sector's growth in the Bình Định province, the Đề Gi port needs an upgrade and a new storm shelter must be constructed to meet the desire to achieve the different master plans. This upgrade and construction is covered by the Khu neo đậu đầm Đề Gi (KND) project. This chapter provides small background information through an introductory section about Đề Gi, in which it describes basic facts and gives a first acquaintance of the port. The introductory section is followed by the importance of the study. This includes the motivation of the research. Furthermore, potential issues of the KND project will be introduced following the research gaps found by the literature review on which the research questions are stated.

1.1 Introduction on Đề Gi

The Đề Gi estuary, located in Bình Định province, central Vietnam (figure 1), houses a fishing port primarily for small vessels. Its natural shelter, the Fresh Water Lagoon (Vịnh Nước Ngọt), provided by an eastern headland, offers protection during frequent tropical storms. Covering 1390 hectares, the lagoon is vital for the local fishing industry, which has grown organically over the years. However, the port lacks official mooring facilities, relying on makeshift jetties. Recent efforts have expanded its infrastructure, including a T-shaped jetty and extensions for better cargo handling.

Access to the Đề Gi port is through a natural access channel. The headland on the north side gives a natural shelter against northern winds and waves. Sedimentation issues at the entrance pose challenges, despite the presence of a breakwater to act as a sediment block. Plans to upgrade Đề Gi fishing Port and add a storm shelter offer significant opportunities for the region's development.

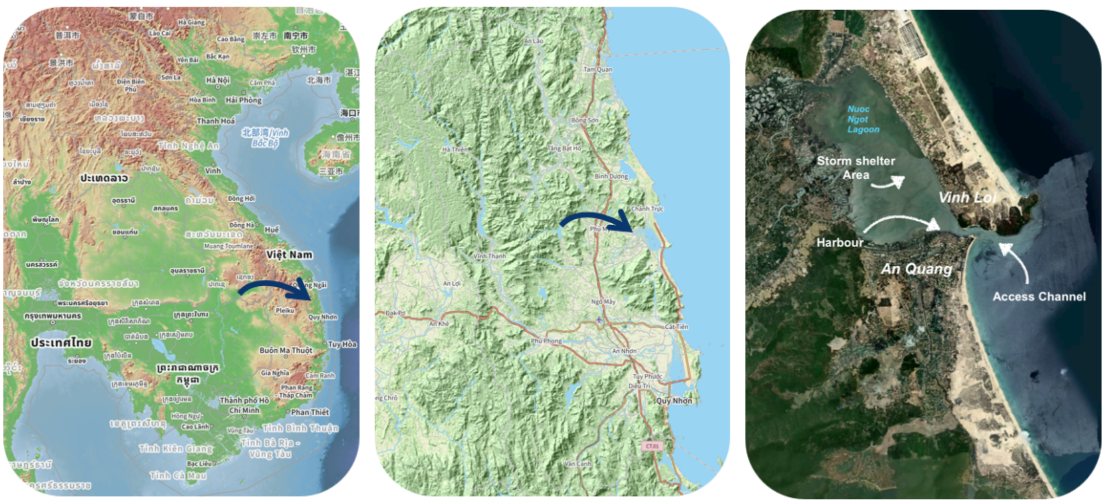


Figure 1: Research area: Đề Gi

1.2 Significance of study

Vietnam has developed enormously after the occurrence of the American War that ended in 1975. Starting in 1986, the country has been actively trying to restore its economy by introducing Đổi Mới (economic reforms) and joining the Association of Southeast Asian Nations ($ASEAN$) in 1995. Both actions are done with the intention of gaining economic growth. To build further on this, in 2000 a bilateral trade agreement (BTA) and in 2016 the Trans-Pacific Partnership with eleven other Pacific countries was signed. This resulted in multiple opportunities that boosted the economic situation in Vietnam.

In 2009 the master plan for improvement of the national seaport system was established (Ministry of Transport 2009). This master plan aims to improve the international character of the country by upgrading its ports up to international standards, enabling increased global trade and boosting the economy. Furthermore, the Ministry of Agriculture and Rural Development ($MARD$) created a master plan for agricultural development in 2012, which describes the goal and vision for agriculture in respectively 2020 and 2030. Agriculture still holds the main share of the country's GDP. In the goal and vision, an increase in the fishing industry by 10 percentage points is anticipated.

In line with these nationwide plans, the Ministry of Agriculture and Rural Development of the Bình Định province published its master plan on socio-economic development in 2009. The Quy Nhơn port is invested in to grow to international standards, according to the national plan on the seaport system. An upgrade of 90 hectre-metres is anticipated. This is at the expense of the current fishing industry hosted in Quy Nhơn which should make room for international shipping. Furthermore, it is expected that the fishing industry is going to grow (according to the national plans) and therefore it is decided to designate the Đề Gi port (together with Tam Quan) as the new main fishing hub of the province. This decision is supported by a master plan on storm shelters in the region, dated in 2015. Storm shelters are placed along the coast with a (natural) shelter function where ships can go during heavy weather, mainly during the monsoon seasons. In the Đề Gi area, there is a storm shelter, as well as port facilities where ships can load/unload their cargo. At the moment the Đề Gi port does not meet the requirements as a regional port to host many fishing boats and is in need of an upgrade which is also incorporated into a plan by the MARD.

To anticipate on the shortenings addressed by the vision of the Ministry, a new project will be constructed at the Đề Gi port to grow in storm shelter capacity. The project makes a big contribution to the development of the socio-economic growth of the port and of the Bình Định Province. The community is strongly dependent on the capital this port generates. Furthermore, daily life is in sync with the rhythm of the port. The focus of this construction project is on hydraulic adjustments to the area. However, how the impact of the construction project on the port system will unfold remains unclear or has not been studied yet. Also, the port system includes multiple disciplines to which the current project and available potential lack research data.

Therefore, the Đề Gi port area is worth doing research based on all the progression in Vietnam and its ambition to achieve more socio-economic stability. This led to this research being part of gaining more knowledge on port systems in their completeness. The fundamental contribution lies in achieving small details and investigating the port area regarding criteria that have been neglected in the past, particularly in the case of the Đề Gi port area. Đề Gi becomes a case study for the research area port systems and potentially can contribute towards a better understanding of other port systems in central Vietnam. Resulting that the conducted research has the ability to contribute to a higher level with respect to port systems and therefore could contribute to promoting the development of fisheries in Vietnam as well as the promotion of the marine economy in general (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

1.3 Research Problem

Considering the fishing industry visions on national and regional levels, as well as the economic development rate of Vietnam in subsection 1.2, the fishery activities in Bình Định province are expected to grow. Based on this, the KND project is approved and will be constructed with the goal to be finished in 2025. Due to the KND project, concerning improvements in the storm shelter and maritime services, even more vessels will be appealed to the Đề Gi Lagoon in the long term, whereas the Đề Gi port might not be resilient enough (subsection 2.5.1). This may result in a deficient contribution to promoting the development of fisheries in Bình Định as well as the promotion of the marine economy in general (chapter 2).

This perception raises two potential problems. Firstly, the KND project focuses on increasing storm shelter capacity and doesn't consider enhancing the network capacity. Upgrading the Đề Gi port and adding a storm shelter will require an expansion of network capacity. Secondly, there's an issue related to the natural access channel, which concerns changes in the vessel fleet mix and the number of vessels calling at the future De Gi port and storm shelter. Research shows that the De Gi estuary faces sedimentation problems which might limit the nautical accessibility of the access channel. Unfortunately, the KND project doesn't address the issue of sedimentation in the port entrance due to a lack of financial support. Looking to the future, a shallow port entrance will become an increasingly significant problem, as for the passage it already is. Vessels with greater depth clearance won't be able to enter the port. This not only makes sailing more difficult but also tarnishes the port's reputation as an unsafe and inaccessible destination, resulting in fewer port calls and reduced transit.

1.4 Research Questions

With the desire to increase the development of the fishing industry on a national and regional level, it is questionable if the overall port system is ready for the proposed future as mentioned in the KND project. At this time, research related to the port's resilience is unknown. Therefore this research provides a first hand on this subject. Accordingly, the main aim of this research is:

Apply engineering methods to understand the port system in order to assess its performance and put this in the context of the socio-economic development of the Đề Gi area and the Bình Định province by means of using an engineering approach to address problems that hamper the anticipated growth of the storm shelter area

To examine how the current port system of Đề Gi is performing now and in the foreseen future, the following main question is investigated:

What is the current performance of the Đề Gi port and storm shelter system, and how can engineering methods be used to assess its potential for future growth within the broader context of socio-economic development?

The main research question is supported by the following sub-questions:

- *How will the current logistic service network perform in the future vision as foreseen by the responsible authorities and how to verify it with an engineering responsible approach?*
- *How to examine the accessibility of the port and storm shelter in the KND project, while ensuring a safe, robust, durable and effective system?*
- *What are the consequences of the port and storm shelter upgrade on the logistical system and on the conditions in the waterway and what impact does this have on the Đề Gi area?*

1.5 Research Objectives

Engineering methods include a very wide range of approaches used by an engineer to solve complicated problems. In order to achieve the main goal, this report focuses on two key aspects of engineering methods: (1) problem identification and (2) investigation and analysis. Problem identification will involve a clear definition of the problems, including identifying the bottlenecks in the system and understanding the needs of the client and users. Investigation and analysis will primarily involve information gathering, including reviewing existing literature related to the problem, collecting and analysing relevant data.

To be more specific how to tackle the research questions and achieve the main aim, the research objects are as follows:

First, an analysis will be carried out on the status of the current logistics service network in the context of the newly foreseen future of the port area distribution. In addition, good accessibility to the port and storm shelter contributes to several aspects, such as economic growth, ease of navigation and a strong competitive position. Therefore, an examination is conducted to assess the accessibility of the access channel from the perspective of safety, robustness, durability and effectiveness. This will result in an assessment of the port system and its role from a socio-economic perspective.

Furthermore, the problems that are impeding the growth of the Đề Gi port and storm shelter will be clearly defined from a transport and hydraulic perspective. This will result in recommendations on which aspects of future research should be carried out.

Additionally, the stakeholders in the Đề Gi port area are going to be identified and the influence of a changing port on their interests will be studied which puts the engineering side of research in a socio-economic context.

Overall, this research will help Đề Gi to become a regional scale fishing port which is known for its well-functioning logistics service network as well as its safe and reliable storm shelter. This image is key to obtaining the desired socio-economic growth of the area.

2 Literature Review

In this section, a summary is made of the literature that is available. This is used to show the relevance of the topic and to gain insight into where the research will fill the gap of the current needs of the government in preparation for the expansion of the storm shelter.

2.1 Short history of Vietnam's economic growth

Vietnam is one of the fastest-growing countries in Asia when it comes to its economy. Things were rather different in the past. After the American War that lasted twenty years from 1955 to 1975, Vietnam was left as one of the poorest countries in the world. For understanding, the GDP per capita was 235 US dollars in the year 1985. A change was needed, therefore the government launched Đổi Mới in 1986 (Tuan n.d.), which entails that the aim of Vietnam is to liberalize the economy and to boost the potential for development. The literal translation of Đổi Mới is restoration, which explains the policies of the government. As a result of the introduction of Đổi Mới, the first steps were mainly to focus on removing self-sanctioned barriers within the country and utilize the potential within the domestic market and actively encourage investment in this sector as well as in the foreign market. After implementing Đổi Mới, a thriving start of restoration is showing.

To build upon this, in 1995, Vietnam was commenced into the Association of Southeast Asian Nations (ASEAN). The ASEAN has set its economic desire and thus the goal to create and accelerate growth in the economies of its members through trading and liberalization of foreign investments. From here on, a base is made to restore the Vietnamese economy. Subsequently, a free bilateral trade agreement (BTA) was established in 2000 with the United States in order to reestablish the economic relationship between the two countries after the events of the American War (*United States-Vietnam trade relations* n.d.). A part of the framework of the agreement that is worth highlighting is that the U.S. government has devoted annually, up until 2012, an appropriation of $ 5 million to support the reformation of Vietnam's economy. Moving 8 years forward after the start of the BTA, in 2008, Vietnam started joining the negotiations of the Trans-Pacific Partnership (TPP). The signing of this agreement happened in 2016 and imposed the purpose of trading with lowered tariffs and removing other trade barriers among the eleven Pacific Rim countries that signed off on the TPP. A few examples of Pacific Rim countries that are included in the deal are Australia, Canada, Japan, Malaysia, and Singapore. To many observers (Perlez 2015), this deal is a geopolitical movement in order to reduce the significance of trading with China and shift to more trading with the United States, with the result of strengthening the economies of the individuals within the TPP, thus also Vietnam. All the above-mentioned key events have contributed to the boosting and the road to restoration of Vietnam's economy. According to the reporting of the World Bank, the GDP growth was yearly between 6% to 7% (excluding the COVID-19 period), rivalling China with these numbers. Up until this day, the current GDP per capita has reached 4164 US dollars in 2022. This demonstrates that Vietnam's economic state is growing. Đổi Mới has created immense momentum for Vietnam, leaving the politicians discussing the emerging challenges that come together with the rapidly rising economy in order to shape the benefits of regionalisation and globalization to its full potential. Due to the happening of the above-mentioned prosperity and contribution from private investors in Vietnam as well as investors from foreign countries, the government is able to allocate the funds. In recent years, the government dedicated roughly six per cent of its GDP towards improving and enlarging its connectivity (Vanham 2018). The percentage is rather notable when compared to other countries in ASEAN, however, this could be explained by the road network plan that the government has set up from 2020 to 2030 with a vision to 2050 (Ministry of Transport 2015). This plan denotes, that infrastructure is an important tool for social-economic purposes and generates a form of social security by continuously investing in it.

In the long term, the desired goal is to gain competitiveness in the economic market. To achieve this, a better road network is needed while also strengthening international corridors at sea and smaller ports.

Besides the road network plan, other decisions and policies were made by the government regarding sustainable agriculture and rural development strategies for the period 2021-2030 with a vision towards 2050 (Ministry of Agriculture and Rural Development 2015a). In this plan, the rural areas of Vietnam are labelled as its country's advantage to develop on economic grounds. These areas are ensuring the nation's food supply and therefore contributing to socio-economic stability. Additionally, the objectives within the last mentioned decision numerous goals are set, such as increasing Vietnam's GDP from agriculture, forestry and fishing, expanding export markets and eventually the wish to compete with the world-leading agriculture countries.

2.2 National vision on (fishing)ports

Nowadays, the world's economy is deeply integrated by transportation over sea. For Vietnam, over 90% of the country's imports and exports volume are via seaports (Nguyen Dinh Viet 2022). This shows that the maritime infrastructure of the country plays a key role in the circulation and exchange of goods. This consequently makes the maritime industry a vital driving force behind the economic development of Vietnam.

Vietnam has several seaports located across the country, of which a few are modern international classes. In 2009 the Prime Minister approved the master plan for the development of Vietnam's seaport system (Ministry of Transport 2009), through 2020 with orientations towards 2030. In this master plan proposal by the Ministry of Transport, one of the key aspects is to develop national general ports in north, central and south Vietnam regions. Especially devote importance to deep water ports and create big gateways to the open sea for attractiveness reasons. One of the key regional seaports in central Vietnam is the Quy Nhơn seaport. According to the approved plans of the Ministry of Transport, the Quy Nhơn port has upgraded its navigation channel to be able to accommodate a 50,000 DWT vessel at full load in the last year (Ministry of Transport 2009). In the period of 2021-2025,(Glotrans 2023) they plan to expand the port by another 90-hectare meters. These construction activities are in accordance with the seaport master plan and clearly reflect the government's urge to build a growing economy with national and international stature.

Besides the master plan for the development of Vietnam's seaport system, the Ministry of Agriculture and Rural Development (MARD) proposed a master plan: Master plan on agricultural production development to 2020, a vision to 2030, which was approved by the Prime Minister in 2012 (Ministry of Agriculture and Rural Development 2012). The viewpoints are that the production development plan must follow the direction of improving productivity, quality, competitiveness, effectiveness and sustainability of agriculture. The objective pleads for the application of science and technology to increase this viewpoint direction to ensure national food security for domestic and export needs. The 2020 agriculture target for Vietnam was structured as: field agriculture (64.7%), forestry (2.0%) and fishery (33.3%). The visioned structure for 2030 is field agriculture (55.0%), forestry (1.5%) and fishery (43.5%). These numbers show a focus shift and investment in the fishing industry. In 2015 another plan of the MARD was approved, the master plan on the system of fishing ports and storm shelters for fishing ships through 2020, with orientations toward 2030 (Ministry of Agriculture and Rural Development 2015b). The planning viewpoints are to attach importance to the construction of fishing ports in association with storm shelters for fishing ships and logistic services formation. As an objective, the plan insists on port and shelter conditions, where high concentrations of fishing ports meet the fishing ships' needs to anchor and use logistic services towards industrialization and modernization. Also, creating international importance and improvement of the capacity of fishing ports are part of the objectives.

2.3 Vision of the Bình Định province

The studied focus area is the Đề Gi fishing port, which is located in the Bình Định province. The Bình Định province in central Vietnam has a historic relationship with the fishing industry due to its geographical location. The province has a coastline that stretches 134 kilometres giving access to 2,500 km^2 territorial sea and an exclusive economic zone of 40,000 km^2. The roughly 6000 boats (in 2020) related to fishing have the option to unload their catch and seek shelter in the ports of Quy Nhơn, Nhơn Châu, Đề Gi and Tam Quan. Furthermore, the abundance of lakes, ponds and lagoons gives rise to various forms of aquaculture, of which shrimp farming takes the largest (75%) share. The total fish production in 2020 is around 250,000 tons, which includes valuable tuna, but also squid and fin fish. The fishing industry employs 350,000 people adding 18,500 billion VND to the regional domestic product, which is 26.1 % of the total regional domestic product (Binh Dinh statistics office 2018).

In 2009 the Master Plan for Socio-Economic Development of the Bình Định province for 2020 with a vision to 2030 was approved under Decision No. 54/2009/QD-TTG dated April 14, 2009, by the Prime Minister. This plan gives detailed steps in order to meet the future vision, especially when looking towards agriculture. Upgrading the fishing industry requires the development of logistic services related to fishing, which translates to completing the fishing ports of Quy Nhơn, Tam Quan and Đề Gi. For Quy Nhơn, the plan is to increase the throughput for international purposes, therefore it is foreseen that Quy Nhơn decreases its (regional) fishing activity (according to Notice No. 333-TB/TU dated October 27, 2021, of Bình Định Provincial Party). Tam Quan and Đề Gi will function as the new main fishing centres of the province. An initial plan to convert Tam Quan and Đề Gi into (satellite) seaports is cancelled due to it not being realistic. The new fishing centres should be based on technology and shift from quantity to quality, especially aiming at aquaculture, which should be associated with ecological environment protection and national sovereignty. Furthermore, local competitiveness is encouraged in order to attract domestic and foreign investors. On a social level, the aim is to improve the intellect, financial status and overall well-being of the fisherman and his relatives (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

The upgrade of the Đề Gi storm shelter is mentioned in Decision No.1976/QD-TTG dated November 12, 2015, approved by the Prime Minister, which describes the planning of storm shelters for fishing boats in 2020 with a vision to 2030. Both Tam Quan and Đề Gi will function as a shelter on a regional level, where Đề Gi will host 2000 vessels up to 300 CV. The Đề Gi port does not meet the requirements yet to be a regional port hosting this amount of vessels and therefore requires an upgrade. The plan to invest in a storm shelter anchorage area was made under Decision No. 4659/QD-BNN-TCTS, dated November 30, 2022 by the Ministry of Agriculture and Rural Development of Bình Định. The latest adjustment to this decision was made on May 19, 2023.

To summarise, the investment in upgrading the Đề Gi port area makes sense, because it is an important contribution to promoting the development of fisheries in Vietnam as well as the promotion of the marine economy in general. The upgrade is in line with the planned socio-economic development of the Bình Định province and national planning of storm shelters for fishing in 2020, with a vision to 2030 (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

2.4 Reference status of Đề Gi

To upgrade the Đề Gi Storm shelter the "Khu Neo Đậu Tránh Trú Bão Đầm Đề Gi" (KND project) is approved. The KND project consists of a dredged channel within the lagoon to allow for bigger vessels to navigate through (figure 2). Because of the hydraulic nature of the lagoon the east side is deeper while the south and west side get shallow due to sedimentation. Therefore, new mooring facilities will be created with anchor posts near Vĩnh Lợi in the east instead of the current location of An Quang in the south to make use of the natural depth and avoid the need for dredging. The embankment of Vĩnh Lợi at the east lagoon shore will be enlarged since this coastline suffers from erosion. The makeshift jetties of An Quang will mostly be deconstructed, while the An Quang jetty as described above will keep its function to serve as an unloading facility for goods and maritime services for the vessels. Due to a new traffic network being realised, a bridge over the mouth of Đề Gi Port is constructed in 2022. This allows for easy road access between the mooring facilities in Vĩnh Lợi and the loading and unloading area in An Quang. At the same time, this bridge is a potential limitation for vessels entering the port because of the clearance height of 9.5 metres. The main span of the bridge consists of a 60-metre-wide channel while the approach spans can also be used by smaller vessels being not much of a width restriction. 400 metres upstream inside the road level will be constructed between DT639 and the location where DT640 reaches the northern district border. Within the urban areas, the road system is incoherent due to the developments over time with many roads being too small in comparison to their class. In the Phù Cát development plan the An Quang and Ngãi An commune are envisioned to be restructured in a cohered manner which also benefits the access of the T-jetty in An Quang to the DT639. The rural roads in the area are fully developed and cohered with their class. Some classes are however too low for the traffic demand. South of the Đề Gi lagoon mouth new tourist areas will be developed between DT639 and the seashore.

Figure 2: Spatial overview of the KND project (Ngoc et al. 2022).

2.5 Research Gaps

2.5.1 Background research gaps

The number of local fishing ships in the province by 2020 contains a total of almost 6000 ships, according to the statistics provided by the Fisheries Sub-Department of the Bình Định province. The Đề Gi lagoon area has the ability to attract ships from other locations along the coast of Bình Định. As stated before, by notice number 333-TB/TU dated October 27 2021 of the Bình Định Provincial Party Committee, a policy of relocating ships at Quy Nhơn fishing port to anchor at the Đề Gi lagoon area is made. Meaning more vessels will be located in the area. According to (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022), the number of vessels to be attracted to the area of the Đề Gi storm shelter is expected to be about 3.144 ships: Phù Mỹ district (1068 units), Phù Cát district (857 units) and Quy Nhơn (1219 units). However, the final report of the KND project expects that the Phù Cát and Phù Mỹ districts will attract only 40% of their total ships to the anchorage area, and so 60% for the vessels at Quy Nhơn and about 400 ships from other locations. A total design capacity amount of 2000 ships is accounted for.

The new planned expansion with a capacity expansion of 2000 units can be seen as a big step in the development of the Đề Gi port and storm shelter. However, based on the vessel statistics provided by the sub-department of the Bình Định Province and the reasoning for the design capacity, the Đề Gi port and storm shelter might be able to fulfil a higher attraction potential in the future (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

Given that only Tam Quan and Fresh Water lagoon are storm shelters in the Bình Định province and that the total number of vessels is about 6000, which is Bình Định at the moment, the number of vessels might exceed the current design capacity or in the future. Also, the Đề Gi storm shelter benefits from its lagoon being a natural and therefore cost-saving refuge spot during storm conditions. This naturally created peninsula is one of the key factors in what gives the Đề Gi fishing port and storm shelter this potential, for managing higher capacity as well as becoming a major socio-economic contributor to the province's fishing industry. Similarly, improvements in logistic services and facilities are not covered by the KND project. Also, the in-depth preliminary research on the considered area is insufficient, and it is also important to address that other disciplines are not covered. Besides the neglected topic, research on the poor accessibility of the nautical access channel of the lagoon has been proven to be a problem (Đỗ 2017). However, due to limitations in the budget, it has been decided that further investigation needs to be postponed.

2.5.2 Identifying research gaps

As mentioned in section 1.2 and previously in chapter 2, many (prospected) changes within the area are based on governmental master plans. The decisions that are rapidly made and therefore influence the local and regional institutions. Given the time frame, several research gaps are observed.

A research gap is defined as a topic or expertise that is missing or has insufficient information to form a conclusion for a question and is therefore limiting the research progress. By identifying a research gap, a new potentially exciting research topic is created.

Hence, the composed research objectives are in order to diminish a part of the research gaps. Beforehand, certain types of research gaps are identified, namely knowledge, conceptual, methodological and data gaps. In short, these gaps entail missing knowledge and understanding, lacking conceptual framework and theoretical understanding, in need of other perspectives and incomplete data sets. The following mentioned research gaps can be classified under one or multiple of these types. After an extensive literature review, it became clear that several topics have not been or were poorly studied, that are taken into this research such as:

1. Too short development horizon considered, only a regional vision up until 2030
   Type: Conceptual and methodological gap
2. The overall functioning of the port system
   Type: Methodological gap
3. Insufficient preliminary research on key aspects for successful operation of the port system
   Type: Knowledge and data gap
4. No examination on the accessibility of the access channel
   Type: Conceptual gap
5. No perspective towards transport system and its logistics
   Type: Knowledge, conceptual, methodological and data gap

3 Research Design

This section focuses on the plan and structure of how the research is conducted. It provide a comprehensive overview of the methods that are utilized. This section ensures that the research is aligned with the research questions and objectives that are defined in chapter 1. Specific data collection methods and the procedure of data analysis will be described.

3.1 Data collection methods

The different research methods that are used to collect the necessary data are: (1) literature studies, (2) field observations and (3) interviews.

In the first stage of the research, the literature studies are used to map the current transport systems using different topography maps. Besides mapping the current transport network, several prospective master plans for regional transportation are reviewed in order to map certain changes in the area. These studies are necessary for a better understanding of the traffic and transport system in the Đề Gi area. Furthermore, in this stage, the literature study is conducted to gather information regarding the hydrodynamic and coastal morphological processes of the Đề Gi area. Identifying these processes is important concerning the accessibility of the port entrance.

During a later stage, literature studies are performed to combine previous research to get an understanding of the system to get a grip on what the problem of accessibility means.

The entire literature review methodology is qualitative, since the performed studies simply serve to interpret the insight of the research area. The gathered data is secondary to the previous studies. In this way, the data collection process is sped up, however, the reliability of data should be taken into account.

Field observations are carried out to better comprehend the theory in practical situations. Due to the shortcomings of preliminary research in combination with the lack of data on the whereabouts and destinations of the goods, the basis of the research on network capacity is exploring neighbourhood surroundings of the Đề Gi area. Furthermore, in the hydraulic field, the hydrodynamic processes are observed using small surveys. Additionally, field observations north and south of the lagoon are preformed to consider if this local accretion problem is part of a bigger problem.

The third research method that applied is interviews. Discussions with locals are held to examine the storm shelter's durability prior to the KND project in order to better understand what happens with port operations during a storm. Furthermore, surveying locals, ranging from fishermen, residents, transporters, port employees and small enterprises assist in defining the current logistic chain of the port and the destination of the goods (caught seafood).

3.2 Data analysis methods

After collecting, the data is interpreted with several analysis methods. To include the aspect of incorporating the socio-economics in a broader context of the area, a stakeholder analysis is introduced to get an understanding of how they relate towards the conducted research. For the network capacity in the area, a qualitative 4(+1)-transport model will be established. The main concept that is used is the 4-step transport modelling and in particular the 4(+1)-transport modelling model (Cats 2022). Due to limited time to gather sufficient data, it is chosen to use the philosophy behind the model and disregard performing the entire model in detail, such that the approach becomes more qualitative. The steps that are included in the model are the trip production/attraction, trip distribution, mode split, time period and network assignment. Data about the hydraulic and morphological processes as well as the previous research on the data is studied and used to analyse the accessibility issues at the Đề Gi area. For the inland logistic services of the port, a qualitative 4(+1)-transport modelling model is established.

3.3 Scope

This research has a time scope of ten weeks including a preparation time of approximately three weeks. It focuses on the Đề Gi port and storm shelter and the surrounding areas located in two districts Phù Mỹ and Phù Cát of Bình Định province. The main focus lies on the prospective expansions of the Đề Gi storm shelter area, the KND project. The overall timeline of this research is shown in Appendix A.

3.4 Resources

For the research, several resources are required, e.g.:

- Equipment
  - Transportation (for the field observation)
  - Maps on paper
  - Audio recording devices
  - Stopwatch
  - Laptops with internet connection
- Access to software/databases or other relevant support
  - TLU research databases
  - Mike21 hydraulic simulation model
  - Binh Dinh government portal information
  - Other TLU information
  - AutoCAD
  - Microsoft Visio
  - Python
  - Google Earth
  - Weather and water data applications
- External support
  - Dr. Lê Hải Trung (TLU)
  - Dr. Lê Tuấn Hải (TLU)
  - Nguyễn Quang Đức Anh (TLU)
  - Civil Engineering department (Coastal and Traffic & Transport) of the Thủy Lợi University

4 Stakeholder analysis

The expansion of the Đề Gi harbour in Vietnam holds great potential for accelerating ongoing socio-economic improvements in the area. The project acknowledges the area's importance and values the contributions of everyone associated with the fishing harbour. This underscores their significance and reliability as a foundation for further exploration of the area's full potential.

To achieve a significant socio-economic impact, it's crucial to have a comprehensive understanding of all groups directly or indirectly involved in the project. Therefore, a stakeholder analysis has been conducted to provide insights. For more detailed information about specific stakeholders, consult appendix B.

4.1 Different stakeholders groups

Most stakeholders can be divided into four big groups namely authorities, port-related, transport-related and geographically nearby stakeholders. Although not all stakeholders can be put into one of these groups in the main text only these four groups will be discussed while individual interests can be found in appendix B.

Authorities
Authorities have the right to assign tasks and responsibilities, allocate and direct resources, make decisions and enforce compliance. The similarity between these stakeholders is that most of these have a relatively high level of impact with respect to other types of stakeholders. However, it could differ between different sorts of authorities. Often, a decision regarding policy is made by one of the concerned institutions and therefore the power is in general quite high.

Port-related stakeholders
These stakeholders are directly dependent on the functioning of the port. Without the port and storm shelter, these stakeholders wouldn't be located in this area. Because most of these stakeholders can move over water, they aren't strictly bound by location. They can potentially shift to another port or jetty, like fishermen, or move a few hundred metres, like on-water aquaculture. They can also repair nets on a different flat surface, like marine services. However, this flexibility can be a point of vulnerability when this group exerts power, potentially leading to a loss of impact.

Transport-related stakeholders
This group includes those involved in the transportation of goods and those reliant on the timely delivery of goods, such as fish processing industries and local markets. Their primary concern lies in the efficiency of the logistics chain. Some emphasise punctual delivery and overall chain performance, while others prioritise the quality of the road infrastructure. For this group, the expansion of the harbour may not always imply significant change. An already busy individual truck driver may simply pass additional goods to other truck drivers. However, a common characteristic among these stakeholders is that a reduction in throughput would have a substantial impact. This could lead to unemployment among truck drivers, a scarcity of fish in local markets, or disruptions in the production process for fish processing industries. Due to variations in scale, a single truck driver lacks the capacity to assert influence, whereas one of the few fish processing industries that accounts for a substantial portion of the fish throughput in Đề Gi wields significant power. Consequently, certain stakeholders within this category can possess substantial influence.

Geographically nearby stakeholders
These stakeholders may not have a clear connection to the port but can be affected by the port's enlargement. Examples include tourist businesses or residents living close to the harbour area or transport corridors. This group is often unaware of the complete plans and may have difficulty with the idea of change in the existing situation. Depending on the economic position of these

stakeholders, they may find it challenging to prove they have been impacted by the project. For example, a roadside resident will have difficulty proving they experienced unacceptable discomfort due to an increased amount of vehicles. Tourist businesses, on the other hand, are a point of interest for authorities and therefore already have a better starting position to discuss points of discomfort due to a port enlargement. This group thus exhibits large differences in the amount of power.

4.2 Power-Interest relations

The stakeholder analysis reveals a dynamic interaction between different parties, each with varying levels of influence and interest in the project. To understand this, a tool called a power-interest diagram is used. It's like a map that shows where each person or group stands in terms of power and interest.

First, stakeholders are sorted based on how much impact they have, creating a hierarchy. Afterwards, a scale to place each stakeholder on the power spectrum while keeping their established order is introduced. This process is repeated to measure the impact of any changes. Combining these scales on different axes gives the corresponding power-interest diagram and therefore a detailed representation of stakeholder dynamics.

This framework allows the stakeholders to be classified into four main groups in the diagram which is depicted in figure 3 namely Key players, Influential, Affected and Marginal players.

Key Players
Key players are stakeholders who have both significant influence and a strong interest in the project's outcome. Some observations on such stakeholders in the power-interest diagram are the districts around the Fresh Water Lagoon. These authorities play a crucial role in deciding changes to the harbour facilities and infrastructure. Similarly, the port authority overseeing the Đề Gi port holds a central role due to its essential responsibility in managing the port.

Influential stakeholders
This group includes stakeholders with considerable power, although they may not express the same level of enthusiasm for the project as key players. Higher-level government bodies are an example. They might view this project as one among many similar initiatives. Nonetheless, their decisions can greatly affect the project's path.

Affected stakeholders
These are individuals or groups who are highly interested in the project's outcome, even though they may not have strong individual influence. This includes fishermen, salespeople on the T-jetty, and transporters. While their individual impact might seem modest, unity is needed in order to create a collective influence before bringing about significant changes.

Marginal players
This category covers stakeholders whose individual impact and interest levels are comparatively small. However, including them is important, especially in considering potential downstream effects. For instance, road users, while individually having limited influence, collectively form a significant aspect that requires consideration, particularly in terms of potential changes in traffic patterns or accessibility.

The power-interest diagram is a vital tool for understanding and visualizing stakeholder dynamics. It provides a clear framework for making decisions and tailoring engagement with stakeholders. This enlarges the understanding and is essential for navigating potential challenges in project execution.

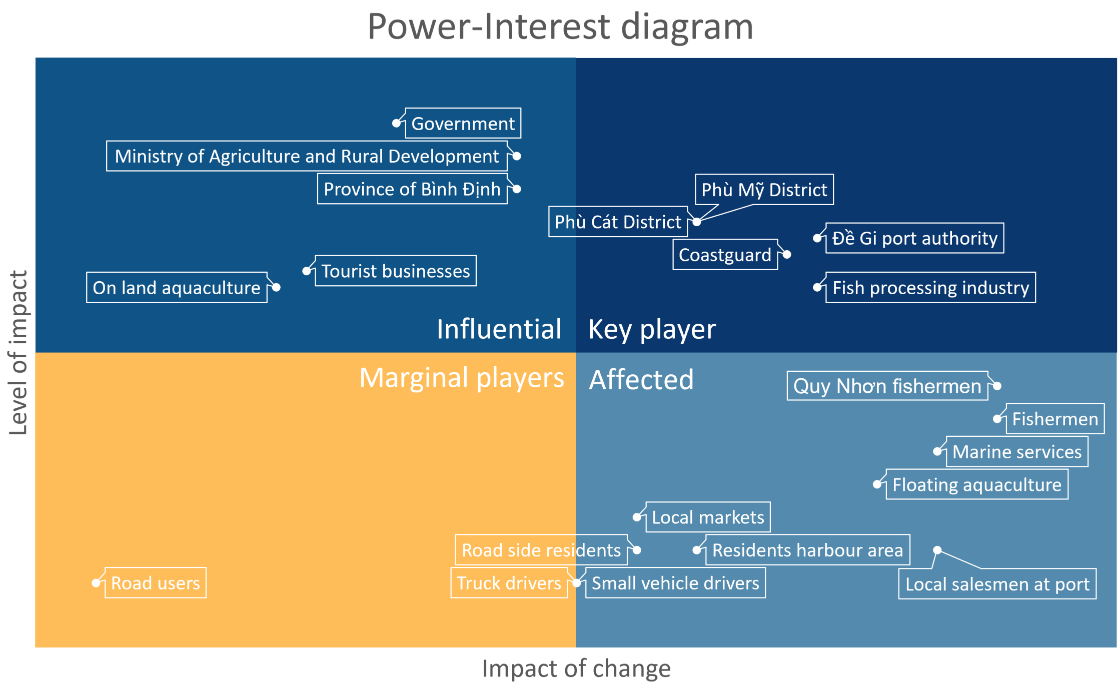


Figure 3: Power-Interest diagram

To help answer the sub-question about the consequences of an increased number of vessels hosted in the Đề Gi port on the logistic and water systems, as well as its impact on the Đề Gi area, the Power-Interest diagram identifies stakeholders with a high level of interest in the changes in Đề Gi. Concluding from the diagram, the government has the most power in the decision-making process in the Đề Gi area, since they are the initiator and funder of the KND project and further studies of the development of the Đề Gi area including this research. The Port Authority has the most power while also having the most impact of the stakeholders with power. Overall, the local fishermen will be expected the most affected, since the port is one of the most important elements in their operation. This relation also works the other way around, since the port depends on the presence of fishing vessels, which gives the fisherman some level of impact. This cannot be said about the local salesmen. The port is their main source of income, but their position is replaceable by concurrence, giving them very little power.

To investigate the socio-economic impact, the second part of the sub-question will examine the consequences on stakeholders related to the Đề Gi area, which will be further discussed in chapter 7 Impacts.

5 Network Capacity

This chapter addresses the following research question:

How will the current logistic service network perform in the future vision as foreseen by the responsible authorities and how to verify it with an engineering responsible approach?

To give insight into the network capacity of the Đề Gi area, the basis is set by observation complemented by modelling of reality, which is used to examine the system performance. Hence, this chapter starts with an extensive site analysis of the research area in the set scope. This gives a description of the freight transport system and the network design of the harbour. Leading to a better understanding of the network organization, operations and transportation around the Đề Gi port. Next to the site analysis, the physical network design and land use are taken into account to describe the reality in order to set the basis for modelling the traffic flow around the Đề Gi port. Modelling this flow focuses on the supply chain and transport needs of the handled goods. The model specifically targets the short-haul trips between the logistic facility, the T-jetty, and its transshipment or closeby end destination. Afterwards, a small first assessment of the performance of the system is conducted on its connectivity, accessibility, robustness and resilience.

5.1 Site analysis on the research area

In this section, a site analysis of the research area will be described. First, the scope area and reasons for this demarcation are described in subsection 5.1.1.

The research area is centred around the Đề Gi port as described in subsection 5.1.1. Within subsection 5.1.2 an elaboration will be given on the patterns that can be observed on a daily basis around the harbour area located in the Đề Gi estuary. After concentrating on the harbour, the road network within the entire scope area will be described in subsection 5.1.4. In the land use analysis of subsection 5.1.5, all (projected) locations with a section traffic demand will be mapped together with locations which are not assumed to have the potential for generating a high traffic demand.

5.1.1 Research area

The research area is the Fresh Water Lagoon, enclosed by three mountain areas on the north, west and south sides, and by the East Sea on the east side. The area includes fifteen communes of which nine belong to the Phù Mỹ district and six to the Phù Cát districts located in the Bình Định province. The research area is given in the figure below (figure 4) encircled with a black boundary, while a more detailed figure regarding the mentioned communes is shown in figure 5. This figure also includes the present markets in the areas which will be elaborated further in the research.

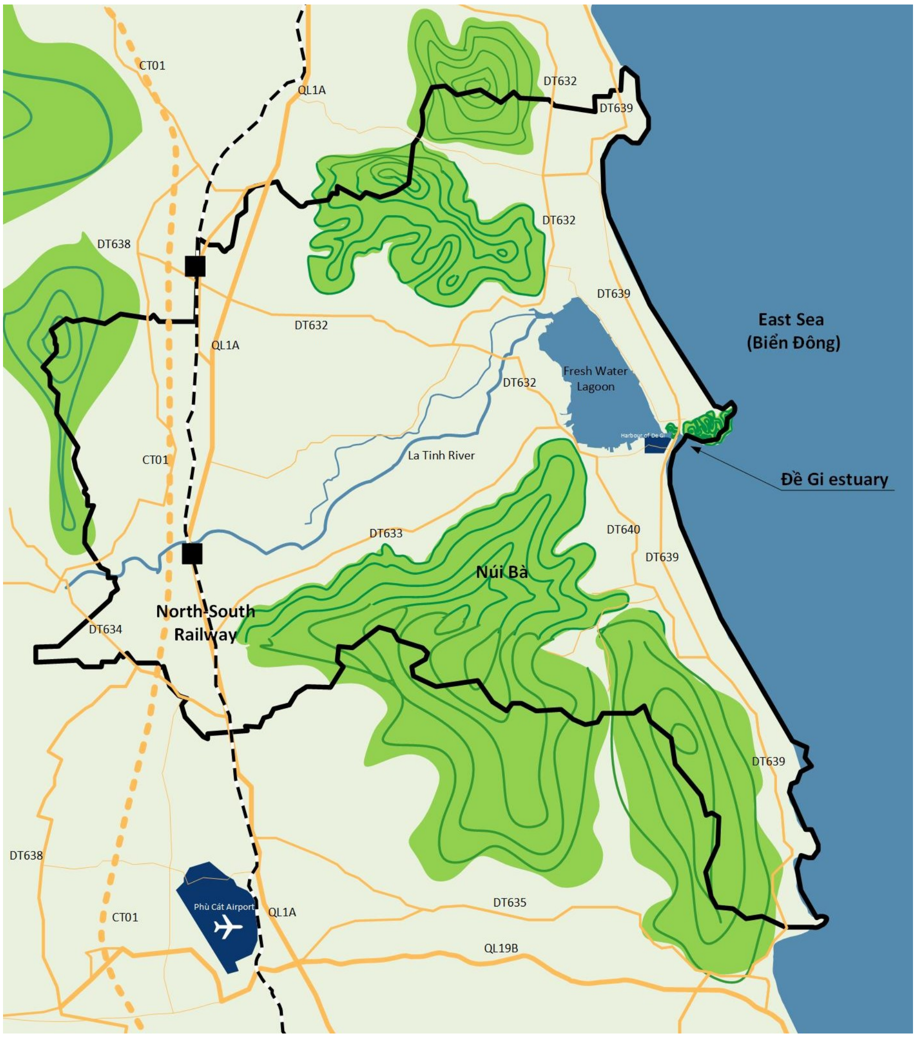


Figure 4: Research area

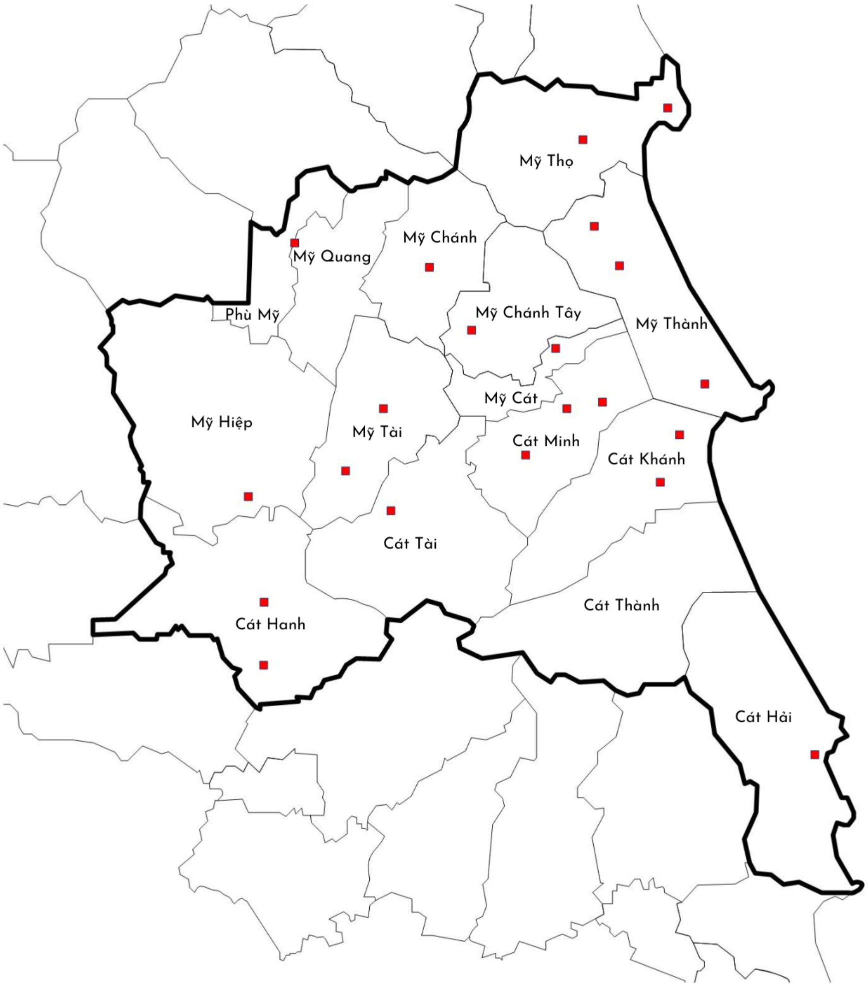


Figure 5: communes with markets

5.1.2 Harbour patterns

Based on observations and interviews (appendix C) multiple patterns can be distinguished that repeat daily within the Đề Gi harbour. These patterns are observed every day despite the potential fluctuations in intensity over time because of the relation with the fishing season. This leads for example to a notable three-month surge in activity during autumn. Additionally, an approximation of a fortnightly peak is distinguished as a result of fishing vessels collectively chasing the same fish schools and fish migration to catch. The observed patterns for the fishing vessels calling at Đề Gi port and patterns at the Đề Gi harbour will be described in paragraph 5.1.2.1 and 5.1.2.2 respectively.

5.1.2.1 Fishing vessels

There are two types of behavioural patterns that can be noted between vessels. These patterns are related to two different groups of fishing vessels. For this research, the groups are described as contracted fishing vessels and independent fishing vessels. Both groups make up approximately half of the ships entering port. First, the independent fishing vessels will be described.

Independent fishing vessels want to sell the catch to the highest bidder. This is only possible in the morning when salesmen are present at the T-jetty of An Quang because the majority of the local markets take place in the morning. As such the fish must be in on time so that it can reach all these morning markets. Therefore independent fishing vessels mostly arrive simultaneously, which leads to congestion at the T-jetty. This causes vessels having to wait sometimes before the catch can be unloaded at the T-jetty and it is too late to sell at local markets. For this reason, all vessels arrive even earlier. Starting from between 4 am and 4.30 am a peak of vessel arrivals can be observed. Around 6.30 am the harbour becomes more quiet again.

Most of the vessels that dock are local vessels and registered in the Bình Định province with a local crew (giao thông vận tải Bình Định n.d.). This results in a relationship of trust between the independent fisherman and the salesmen as will be explained in more detail in paragraph 5.1.2.2. Small vessels with a capacity of around three to five tons may have been only one night at sea but the majority of fishing vessels have been fishing at sea for half a week up to two weeks. After the unloading of the fish, most vessels will go towards the nearest navigable location to the fisherman's homes. This may be anywhere in the Fresh Water Lagoon and it results in hotspots of anchored vessels, shown in figure 6.

Figure 6: Current mooring locations under normal conditions

The second group are the contracted fishing vessels. This group has on average less bonding with the Đề Gi area and will enter a port whenever the hold is full. Therefore this group arrives mostly evenly over the day. In their approach to a fishing port, they call the contracted company to arrange the handling and the pick-up of the catchment by a truck at the desired moment and port. This process will be further elaborated in paragraph 5.1.3.2. The mentioned group has less bonding to the Đề Gi area, as the independent fishing vessels. After unloading the fish, these vessels are most likely to leave the harbour immediately to continue fishing and arrive back home when the contract permits the crew to go home.

All vessels that want to leave the harbour will first bunker. This is done by bunker vessels, of which most will supply in the Đề Gi estuary on the water. It is also possible at other locations within the lagoon but the bunker vessels have their home port in An Quang. After bunkering enough diesel for their voyage, collecting ice to keep the fish fresh for multiple days is key. This can be done at the north side of the Đề Gi estuary where it is also possible to collect LPG tanks for onboard installations if necessary. Those are not supplied at the T-jetty due to fire hazards. When the vessel is full of ice, it is ready to depart for fishing.

Most vessels fish at night since fish schools swim closer to the surface when it is dark which makes catching fish easier than during the day. This also means that during the afternoon and evening, it is busy with vessels leaving the harbour while in the morning it is busy with vessels entering the harbour.

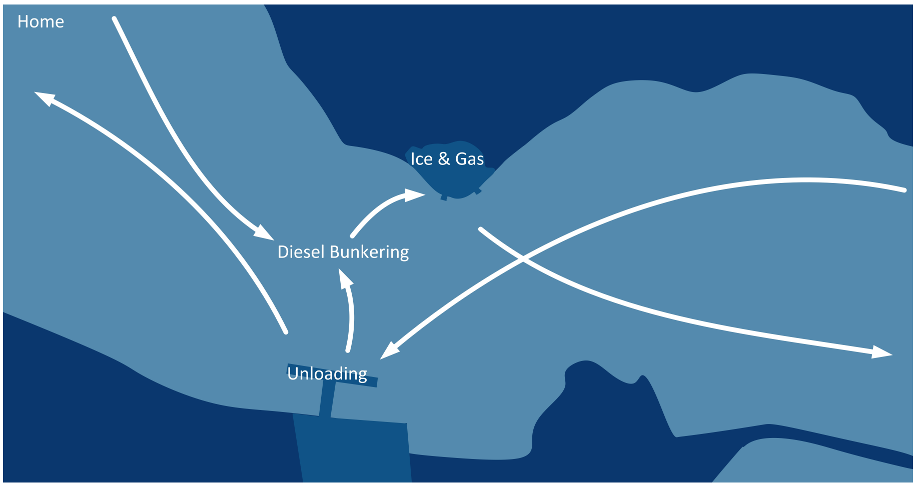


Figure 7: Patterns observed by ships calling the Đề Gi port

5.1.2.2 T-Jetty

The main part of the Đề Gi harbour is the T-jetty. Here, all ships arrive for unloading, it is the central point of all logistics processes in the harbour, but it also represents the central node in a wider supply chain network that supports freight transportation and in this case fish. The T-jetty may be seen as a pick-up point due to transportation mostly done by individuals. This makes it a busy location with many activities in a small space. Besides the unloading of ships, other factors like salesmen, buying and distributing fish, and motorists of different types of transportation vehicles are present.

When fishing vessels moor at the T-jetty the catch will be sold before unloading of the vessels starts. Fishing vessels are mostly selling the complete catch at once to the highest bidding salesman or to the specific salesman they always do business with. Most salesmen resell it again in smaller portions to individuals on two or three-wheelers. For smaller ships (seven to ten tons of fish) it is also possible to sell the complete load of fish directly to a truck driver. Not contracted trucks which buy a complete shipload are mostly present in the early morning because they mostly supply (multiple) morning markets further away and therefore have a longer journey ahead. For contracted ships, the process works similarly to small ships that are selling directly to a truck as described before. But the ship's catch tonnage is higher and thus the required truck must be bigger.

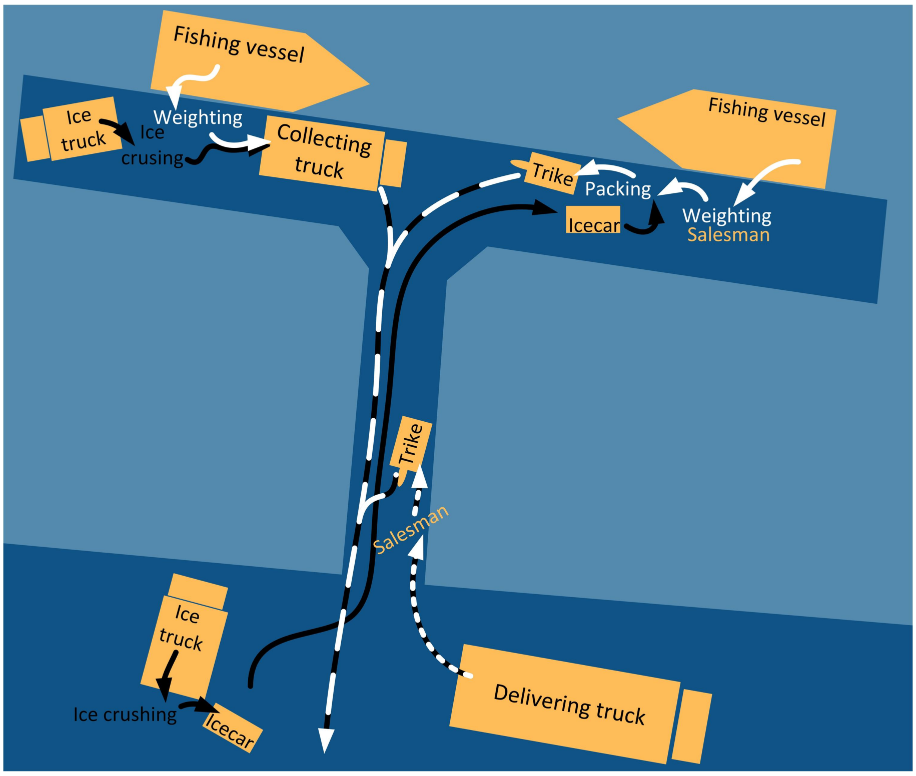


Figure 8: Patterns observed at T-jetty

During the unloading of the fish from the vessel, the catch undergoes weight measurement. To facilitate this, the ice initially present is removed. Subsequently, the fish is re-immersed again in fresh ice, resulting in the need for ice at the T-jetty. The supply is handled by ice trucks that are present at the landing of the jetty where also the crushing of the ice is done by special machines. In order to transport the ice closer to the vessels, handcarts are used to transport smaller amounts. In cases when fish is directly handled into the truck from a vessel, the ice truck enters the T-jetty. The Ice trucks transporting the ice enter and leave the scope area via the DT639 in the south. As observed on average one ice truck seems to be needed for every nine tons of fish catch.

At the harbour not only do fishing vessels arrive with fish, also trucks from other locations arrive with different species of fish. When the fish is unloaded from the trucks the same process that is described before for fishing vessels arriving in the harbour starts.

Salesmen can be found both at the T-jetty's landing section, where they resell fish from incoming trucks and at the T-jetty's forefront, where they sell fish from fishing vessels. For use of the harbour facilities, a fee is required, and the expenses are contingent upon the specific vehicle or job, which can be found in table 1 for reference.

Type	Price [vnđ]
Small vessel	100,000
Large vessel	200,000
Motorbike	2,000
Trike/Tuk-Tuk	5,000
Small truck	10,000
Large truck	20,000
Salesman	10,000

Table 1: Harbour fees of the Đề Gi harbour

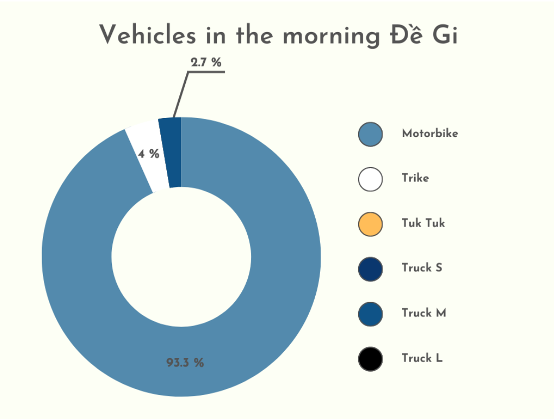
5.1.3 Transport vehicles

Within the transport network, multiple modes are used to transport all fish. Certain modes are only used for certain nodes as will be later discussed in paragraphs 5.1.3.2 and 5.1.3.3. All used modes are displayed in figure 9 with examples of every vehicle from inside the scope area in appendix D.1.2. It is important to notice the extensive difference in both carrying tonnage capacity and PCU (passenger car unit). The ratio between these units is for both motorbikes and trikes 1 while, except for the ice truck, the bigger the vehicle the more efficient in terms of consuming road capacity the transportation becomes.

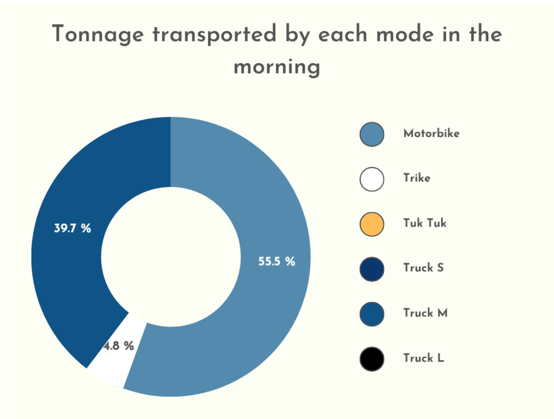
Figure 9: Visualization of all different vehicles utilised for harbour-related transportation

5.1.3.1 Vehicle count

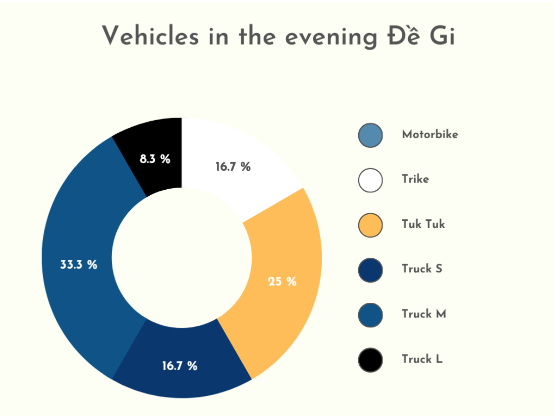
During one morning period and one evening period, all transportation vehicles leaving the harbour area have been counted. In this count the type of vehicle and for trucks also the location of license plate registration have been noted. While during the morning observation, only three cargo trikes were spotted and no cargo tuk-tuks, observations of other days when no count was conducted show cargo tuk-tuks and cargo trikes have a significant share in the mode mix present at the Đề Gi harbour the results can be seen in figure 10. The morning and evening counts have been added together in sub figure10e and 10f. This also includes all vehicles captured by camera within the same 24-hour period while vehicle count was not the main objective. Although the data has been enlarged, in this manner it is not complete.



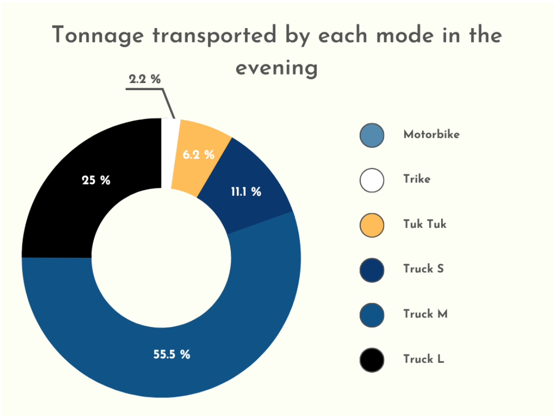
(a) Vehicles count during morning peak



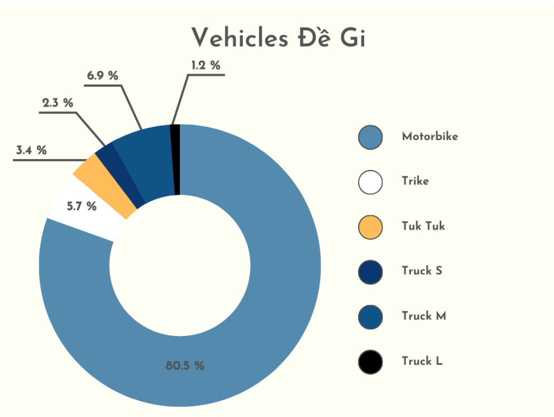
(b) Tonnage of fish exiting Đề Gi harbour in the morning



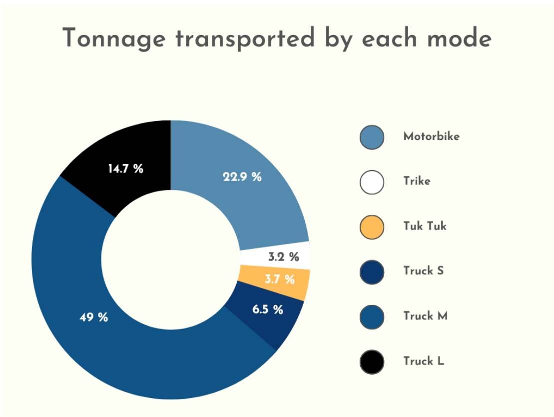
(c) Vehicles exiting Đề Gi harbour in the evening



(d) Tonnage of fish exiting Đề Gi harbour in the evening



(e) Vehicles exiting Đề Gi harbour



(f) Tonnage of fish exiting Đề Gi harbour

Figure 10: Vehicles and tonnage exiting the Đề Gi harbour

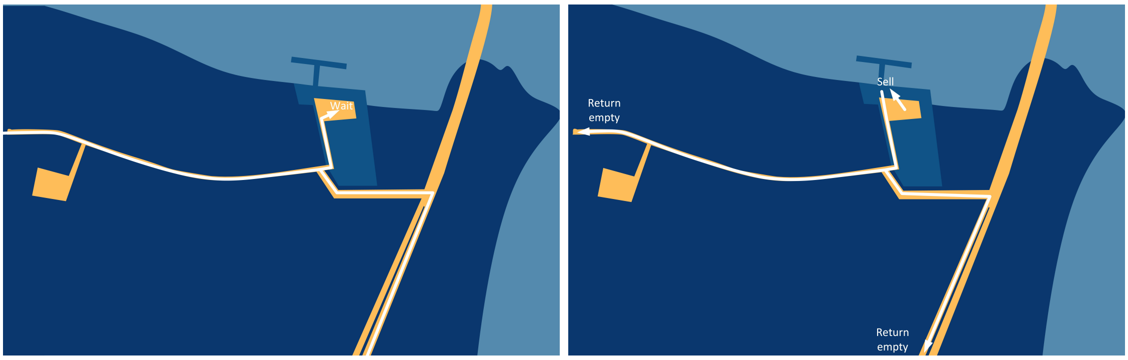
5.1.3.2 Trucks

In the Đề Gi harbour, four types of trucks are present; small, medium, and large-sized trucks for fish transporting and small ice trucks for only supplying ice. Due to the different sizes, not all trucks can fulfil the same objective and therefore transportation to different locations will be done with different sizes of trucks. Small and medium-sized trucks heading to Đề Gi mainly come from outside the Đề Gi area but mostly from within the Bình Định province, which is manually observed by noting the first numbers of the licence plate which represent the registration province of the trucks. Large trucks, however, have mostly licence plates from other provinces. Synchronized with the vessel patterns, truck patterns can be noticed depending on the time of day. Three major groups can be distinguished, contracted trucks that collect the fish from contracted fishing vessels. Delivering trucks, trucks that only deliver fish to sell in the Đề Gi harbour, and collecting trucks which buy the fish in the Đề Gi harbour and drive fish to nearby markets or other locations where fish will be sorted for morning markets.

At any time during the day, contracted trucks arrive simultaneously with a contracted vessel that has called in its arrival with freshly caught fish in the Đề Gi port which must be transported towards a fish factory or other contracted facility. These trucks may have waited for a short while until the vessel arrived. However, this is always a short period of time. After this unloading of the fish from the vessel into the truck happens such that it is ready to depart to their destination. The share of contracted trucks within the Bình Định province is quite large, yet the share of fish leaving the province is larger with less amount of larger trucks. Northern province-bound trucks and approximately two-thirds of the trucks within the Bình Định province depart west over the DT633, while most southern province-bound trucks and one-third of the Bình Định province-bound trucks depart east and turn south on the DT639. A neglectable amount of trucks go east and turn north on the DT639.

The second group, delivering trucks, mostly arrive in the evening at the Đề Gi port area. The contents transported are fish species that are not caught in the waters surrounding the Đề Gi port. Whenever a truck enters the port area in the evening, the truck is parked overnight such that in the morning the fish can be sold. The selling process is identical to the process of vessels that bring in caught fish in the morning. A detailed description is going to be elaborated on in section 5.1.2.2. Due to these events, the diversity of available fish has increased in the area, resulting in two or three-wheeled vehicles also supplying the local markets with a wider variety of fish.

The third group of collecting trucks is only present in the early morning, these are small and medium-sized trucks that transport fish to places in a wider area around the Đề Gi port. All these smaller trucks observed at this time are from the Bính Định province. Most are supplying local markets more inland which lack the possibility to have two or three-wheeled vehicles making multiple trips in the morning to supply in time.



(a) Evening **(b)** Morning

Figure 11: Observed truck movement patterns in Đề Gi

5.1.3.3 Two or three-wheeled vehicles

For short distances, mostly two or three-wheeled vehicles are used. These types of vehicles are either motorbikes, cargo trikes, cargo tuk-tuks and to a lesser extent motorbikes with trailers. For this research, the motorbikes with trailers will be merged with cargo tuk-tuks. Although different in appearance and size all have a similar pattern.

The main focus is on buying the fish at the harbour and selling the fish to salesmen at local markets. Depending on the distance a bigger vehicle is used since on larger distances fewer trips can be made and a larger capacity is needed. For the An Quang market (less than a kilometre from the Harbour) nearly all transport is done by motorbike, but towards the Cát Hanh markets (twenty-one kilometres) predominantly cargo tuk-tuks are used. When the goods are delivered at the local markets, almost all drivers will directly turn around towards the harbour to collect more fish and repeat the process until the peak of sales at the markets is over and market salesmen are not prone to buy more fish anymore, this happens around 7.30 am.

5.1.4 Traffic Network

In the research area, there exists a comprehensive road network comprising various Vietnamese road types. For all road sections in the research area, the characteristics will be analysed using the data collected from the field observation. These data have been observed and manually measured. On top of this, the capacity for the road sections within the research area will be defined. A visual representation of the traffic infrastructure in the research area is presented in figure 12.

Figure 12: Traffic network of the area

5.1.4.1 Road characteristics

Within the scope of our research area, four main categories of road infrastructure are observable: national highways (QL), provincial roads (DT), and other minority roads such as the local roads (D) and the planned north-south motorway (CT01).

In the research area, two national highways are notable: QL1A in the west and QL19B in the south. These highways primarily serve as vital transportation links connecting Đề Gi harbour to external regions beyond the research area. QL1A predominantly facilitates transportation between provinces in a north-to-south direction, including Quảng Ngãi and Phú Yên. In contrast, QL19B runs from west to east, mainly used for the transportation of goods and passengers from Bình Định to Gia Lai or Đắk Lắk. It is important to note that QL19B, while not officially part of the research area, plays a significant role. However, this national highway is an important connection right to the south of the research area, it is necessary to include QL19B in the analysis of the traffic network.

The predominant component of the traffic network in the research area comprises provincial roads, see figure 5.1.4. These provincial roads form the primary transportation infrastructure within the study area. In contrast to the national highways, provincial roads typically exhibit superior capacity and quality, owing to their relatively recent completion based on modern guidelines mandating for wider roadbeds. Notably, DT639 represents the most recent addition to the provincial road network and traverses the surroundings of Đề Gi harbour. Consequently, it has a large impact on the accessibility of the harbour and its surroundings.

A smaller portion of the traffic network comprises local or district roads, which are not officially categorized as motorways, national highways, or provincial roads. These local roads predominantly facilitate transportation within the Đề Gi area, serving local and district-level mobility needs.

Additionally, there are plans for the future construction of the national motorway CT01, which is set to be positioned parallel to the existing national highway QL1A in the western part of the area outside the town. This development is expected to enhance hinterland connectivity and alleviate traffic congestion on QL1A, offering potential benefits in terms of traffic flow and efficiency (Bộ Giao Thông Vận Tải 2022).

The outcomes of the traffic network analysis are presented in the table below. For comprehensive information about each road section within the research area, please refer to appendix D.1.

Road section	Direction Separation	Side line	Lanes [#]	Width [m]	Street lighting	Road guidance	Give way [m]	Trucks allowed
Chánh Trực - Chánh Thiện	Marking	No	2	5.8	No	Poles	0-1	No rush
Chánh Thiện - Phù Mỹ	Marking	No	2	7.5	In commune	None	1-2	Yes
DT633								
An Quang - Ngãi An	Barely	No	2	5.2	Limited	None	0-1	Yes
Đức Phổ - Chợ Gồm	Marking	No	2	5.2	In commune	None	0-1	< 10T
DT639								
Mỹ Thành – Cát Tiến	Separation	Yes	2×2	2 × 9.5	Yes	Curb	0	Yes
DT640								
Chánh Thiện - Đức Phổ	Marking	No	2	5.5	No	Ditch	0-1	Yes
Đức Phổ - Ngãi An	Marking	No	2	5.7	Yes	Barier ditch	0-1	< 15T
Ngãi An - Tân Thắng	Marking	No	2	5.4	In commune	None	0-1	< 22T
Other								
Vĩnh Lợi - cầu Đề Gi	No	No	1	0.5	No	None	1-2	No
Vĩnh Lợi - DT632	Marking	No	1-2	3.5 5.5	In commune	None	0-1	< 22T
Chánh Trực - Tân Thành	No	No	1	4.1	No	None	0-1	Yes
Tân Thành - Mỹ Thành	No	No	1	8	No	None	0	Yes
Chánh Thiện - QL1A	No	No	1	4.1	No	None	0-1	<10T
QL National highways								
QL19B	Marking	No	2	5.8	In commune	Negligible	0-1	Yes
QL1A	Separation	Yes	1×2 2×2 2×3	1×7 2×11.5	Yes	None	0	Yes
Future roads								
Ngãi An - DT639	Separation	Yes	2×2	2 × 9.5	Yes	Curb	0	Yes
Mỹ Thành - Phù Mỹ	Separation	Yes	4	11	Yes	Guard rail	0.5	Yes

Table 2: Road characteristics

5.1.4.2 Road capacity

When the road characteristics of the road sections are defined, the capacity for each link in the traffic network can be determined. This is accomplished by applying the capacity equation 1 from the Indonesian Highway Capacity Manual (Directorate General of Highways 1993), since the Indonesian traffic conditions are almost the same as in Vietnam.

The capacity equation for each road section in the network is given as follows:

$$C = C_0 \times F_W \times F_{KS} \times F_{SP} \times F_{SF} \tag{1}$$

With:

$$C = Capacity\, of\, the\, section$$

$$C_0 = Base\, capacity$$

$$F_W = Carriageway\, width\, factor$$

$$F_{KS} = Effective\, shoulder\, width\, factor$$

$$F_{SP} = Directional\, split\, factor$$

$$F_{SF} = Side\, friction\, factor$$

The specific factor values necessary for these capacity calculations are determined by means of the road characteristics from table 2. The detailed calculation of these factors is provided in detail in appendix E. The capacity of the road sections in the network has been computed and is provided in table 3, with the visualisation in figure 13.

Road section	Capacity (PCU/hr)	Road section	Capacity (PCU/hr)
DT632		**QL National highways**	
Chánh Trực - Chánh Thiện	1953	QL1A	6129
Chánh Thiện - Phù Mỹ	2739	QL19B	1730
DT633		**Other**	
An Quang - Ngãi An	1510	Vĩnh Lợi - cầu Đề Gi	175
Đức Phổ - Chợ Gồm	1580	Vĩnh Lợi - DT632	1052
DT639		Chánh Trực - Tân Thành	1328
Mỹ Thành – Cát Tiến	6023	Tân Thành - Mỹ Thành	2585
DT640		Chánh Thiện - QL1A	1328
Chánh Thiện - Đức Phổ	1696	**Future roads**	
Đức Phổ - Ngãi An	1911	Mỹ Thành - Phù Mỹ	3229
Ngãi An - Tân Thắng	1657	Ngãi An - DT639	6023

Table 3: Road Capacity

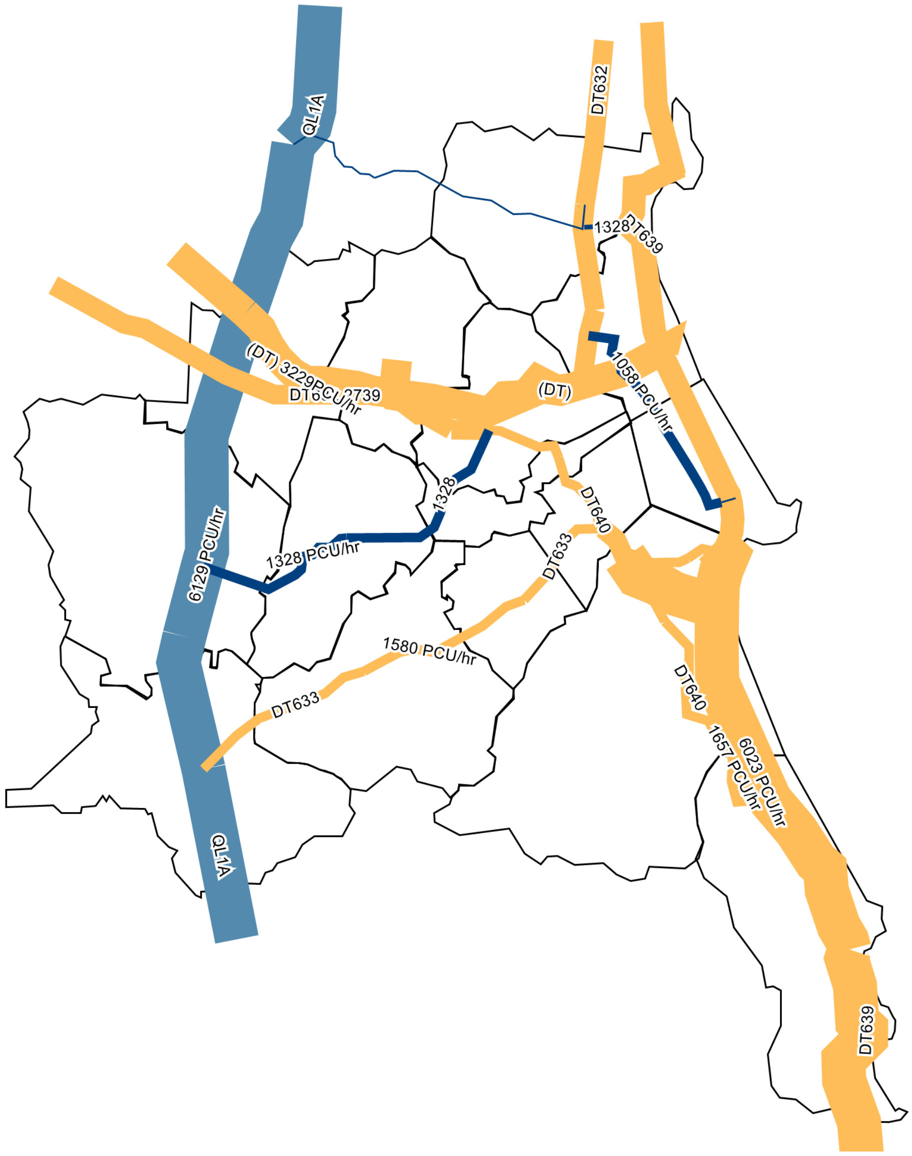


Figure 13: Capacity of the road sections

5.1.5 Land use

The land use within the designated research area is categorized into three primary categories: agricultural land, non-agricultural land and unused land. The area encompasses fifteen communes with a total area of 48,976 hectares (tỉnh Bình Định 2022a & tỉnh Bình Định 2022b). The La Tinh River flows through the heart of the research area, acting as the natural divider between the two districts. Primarily designated for water aggregation, rendering it an indirect land use feature with a barrier effect that leads to fragmentation.

Agricultural land use
The largest portion of land in the research area falls under agricultural purposes, accounting for approximately 80% of the total land use (tỉnh Bình Định 2022a). This category encompasses land dedicated to agricultural, forestry and aquacultural productions, with a smaller portion allocated for the salt industry. Given the predominantly rural nature of the region, agricultural land is spread across the entire research area, with a concentration of agricultural production in the western part and a higher prevalence of aquacultural land use in the eastern region, particularly around the Fresh Water Lagoon (see figure 14).

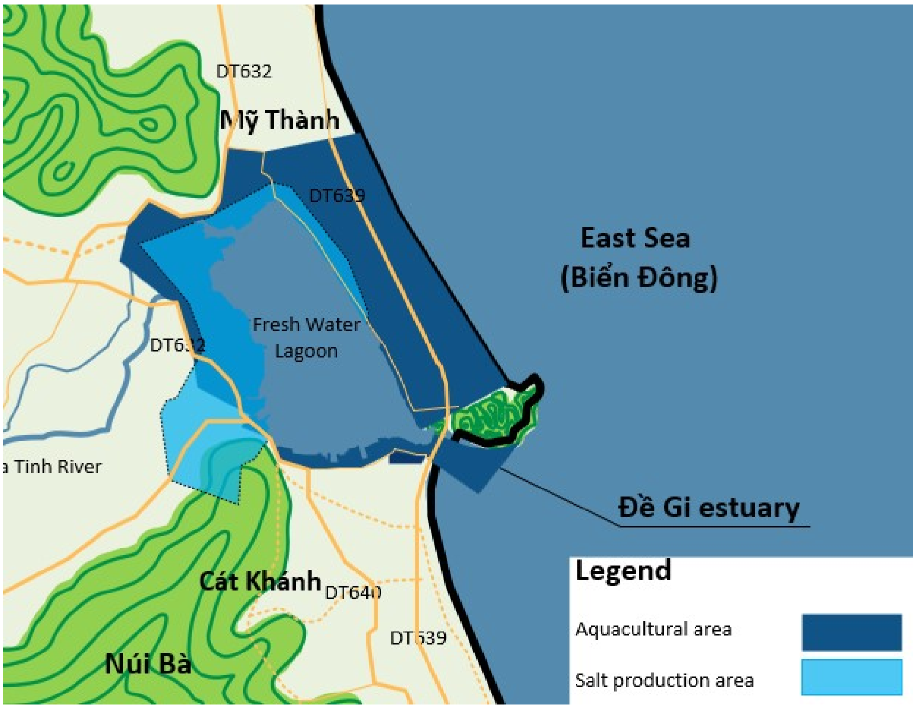


Figure 14: Aquaculture and salt industry areas

In terms of agriculture, the production process remains decentralized and spontaneous, covering activities such as rice and maize cultivation, despite challenging soil and irrigation conditions for these crops. Additionally, there is cultivation of perennial industrial crops, fruit trees, and production forests, primarily focused on resin and eucalyptus for paper production. Other agricultural activities include vegetable farming, fruit tree cultivation, tea farming, aquaculture, and livestock farming, which includes cattle, pigs, and poultry. This region is particularly well-suited for the cultivation of industrial crops, production forestry, and large-scale livestock farming, owing to its potential and soil quality.

To support this category of land use in terms of transportation, a robust infrastructure for goods transportation is essential. These areas often serve as origins in the transportation network. The elaboration on this is going to be carried out in section 5.2.

Non-agricultural land use
The second land category is characterized as non-agricultural, encompassing residential areas, specialized zones for other specific purposes, bodies of water, and religious sites. This category occupies approximately 16% of the total research area, with a primary concentration in urban regions, notably in the northwestern part of the scope area.

Rural development aligns with the natural flow of river and stream basins from east to west. Residential areas are typically arranged in clusters, mainly within the central regions of the commune. Furthermore, they are situated in long-established residential zones that benefit from favourable land availability, infrastructure, and essential social amenities catering to both residents and businesses. The population is dispersed along inter-district and inter-communal roads, as well as on elevated terrain situated between river and stream basins flowing from east to west. High population density is observed in areas adjacent to national highways and provincial roads, capitalizing on diverse business opportunities. The densely populated areas are given in figure 15.

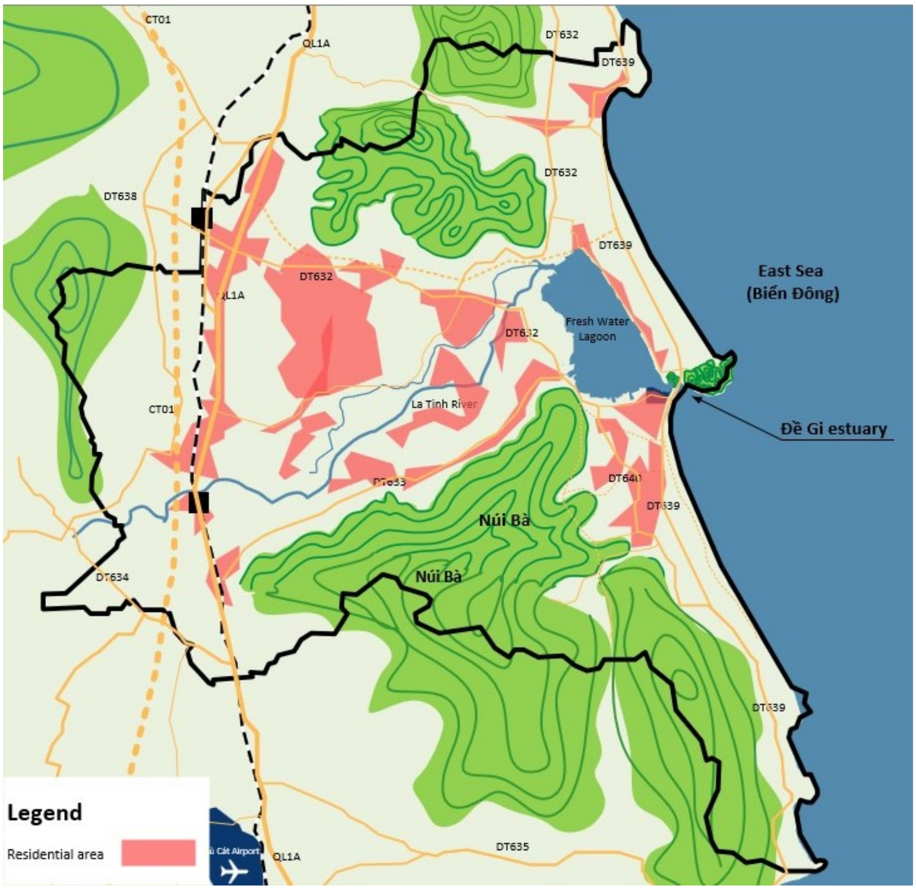


Figure 15: Densely populated areas

The urban development in this area closely integrates with the expansion of industrial and small-scale industrial sectors, craft villages, trade, and services. It also involves the cultivation of industrial crops, fruit trees and advanced technology industries. Concurrently, there are plans for tourism development that emphasize historical and cultural heritage sites.

The transportation networks connect these population centres, serving as both origins and destinations within the people and goods transportation network. This region holds a pivotal role as the town's administrative centre and commercial services have thrived owing to its dense population and the presence of National Highway 1A (QL1A) traversing through it.

Unused land
The unused land accounts for a relatively minimal portion of the total area, approximately 3%. This category includes level terrain, unused mountainous terrain and non-forested rocky mountains. The transportation infrastructure is notably constrained in this region. This classification of land use is primarily situated in the mountainous areas to the north and south of the research area, as well as along the coastal region, particularly at the Đề Gi estuary, notably in the Lâm Sơn hill area.

Future land use development
In accordance with the development plans outlined in *Quy hoạch xây dựng vùng huyện Phù Cát đến năm 2040, tầm nhìn đến năm 2050* n.d. and *Đồ án quy hoạch xây dựng vùng huyện Phù Mỹ đến năm 2035* n.d. of the Phù Mỹ and Phù Cát districts, the research area is planning for three key transformations: agricultural and industrial development, urban expansion and the growth of tourism-related infrastructure. Nevertheless, it is anticipated that the urban and tourism developments will exert the most significant impact on the traffic and transportation network within the research scope.

Urban development will be concentrated in three key locations: Phù Mỹ town, Mỹ Chánh, Cát Hạnh and Cát Khánh communes. These locations will undergo a mix of urbanization, high-tech agriculture ventures, eco-tourism and supporting industries. Phù Mỹ town will experience an urban renewal with a focus on preserving flood drainage basins and stabilizing agriculture practices. Additionally, this area is going to witness industrial development will also take place here, including the creation of a high-tech agricultural hub in the western region, linked to eco-tourism attractions. The Cát Khánh area will pivot towards tourism, marine economic services and community-driven tourism, capitalizing on its close proximity to the Fresh Water Lagoon and the Đề Gi port. Meanwhile, Cát Hanh, an industrial urban area, focuses on trade and services linked to the Hòa Hội industrial park. While being located on National Highway 1A, it plays a core role in the Northwest sub-region, offering public services, consuming local agricultural products, and supporting coastal tourism routes and fisheries logistics.

In the context of tourism development, DT639 is designated as a tourism and coastal economic services corridor, connecting with the tourist route from Quy Nhơn to create a continuous tourism route along the eastern side of the province. All projects and plans are oriented towards the development of tourism linked to the coastal ecological space. Therefore, the areas of Mỹ Thành, Cát Thành, and Cát Hải, situated along the coastal road with coastal land resources and scenic landscapes, have seen the development of numerous tourism projects, with further development anticipated. Additionally, the mountainous terrain of Núi Bà is also going to be one of the regions for tourism development, along with existing natural tourist areas and new eco-tourism destinations.

The main urban and tourism development areas are visualised in the figure below.

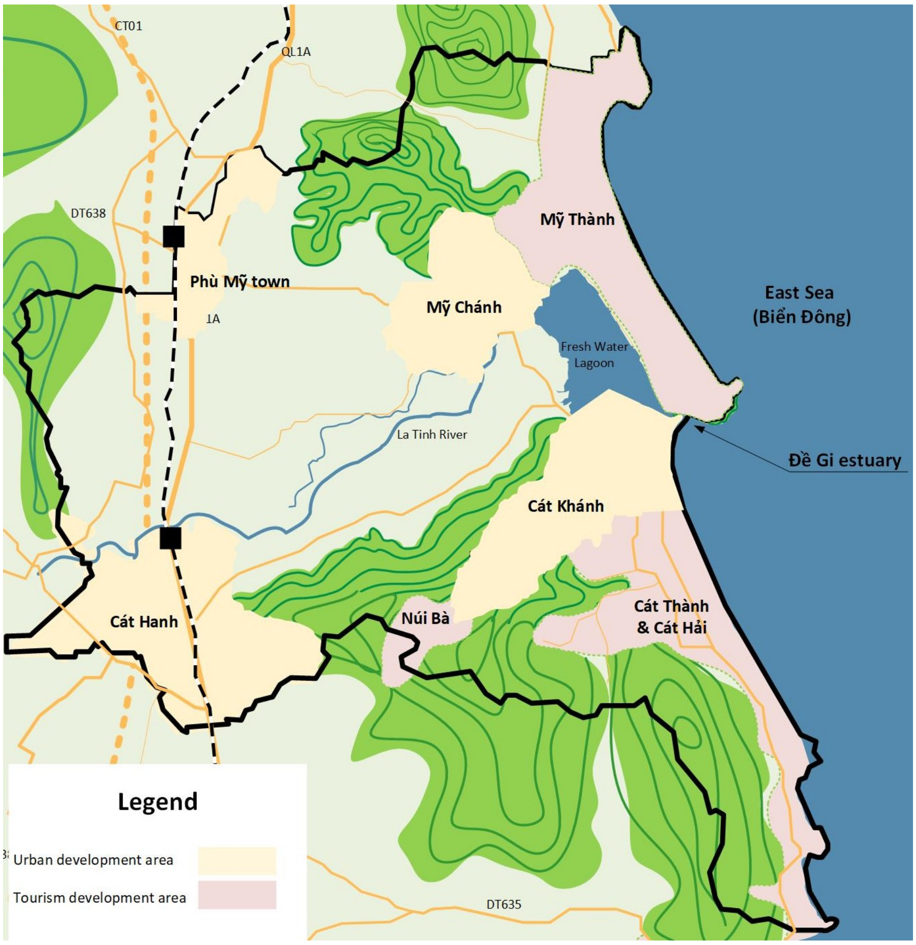


Figure 16: Urban and tourism development areas

5.1.6 Demography

The demographics for the scope area are from two different districts since the research scope includes both Phù Mỹ and Phù Cát district. Therefore it is needed to entail the demographics of these districts using tỉnh Bình Định 2022b and tỉnh Bình Định 2022a. The statistics from these development plans are dated up until 2020. The population was back in that time 183,557 and 161,667 persons for respectively the Phù Cát and the Phù Mỹ districts. In recent years, in the entire province, a small decrease in population growth has been witnessed. However, concerning the districts in the research scope, it is the other way around. Leading to the natural population growth rate being estimated at 0.72% per year and predicting a larger population in the involved districts (People's Committee of Bình Định 2022). Currently, the population density is also increasing, in 2022 averaging around 216 persons/km^2 in Phù Cát and 291 persons/km^2 in Phù Mỹ (People's Committee of Bình Định 2022). For the scope of the project the future scenario with a set horizon of 2050. With the estimated 0.72% yearly growth rate the population growth from 2020 to 2050 is expected to be 24.01%. Further details on the demographics per commune now and in the future scenario are visible in table 4.

	Commune	current population [p]	2050 population [p]	Future population density [p/km2]
Phù Mỹ	Mỹ Thọ	11,171	13,854	499
	Mỹ Thành	6,475	8,030	391
	Mỹ Chánh Tây	3,861	4,788	203
	Phù Mỹ	11,410	14,150	1,316
	Mỹ Chánh	12,325	15,285	699
	Mỹ Hiệp	12,325	15,285	268
	Mỹ Cát	5,704	7,074	800
	Mỹ Tài	8,156	10,115	360
	Mỹ Quang	6,475	8,030	399
Phù Cát	Cát Hanh	13,715	17,009	380
	Cát Tài	9,721	12,055	311
	Cát Minh	15,001	18,603	732
	Cát Khánh	13,187	16,354	532
	Cát Thành	8,252	10,234	245
	Cát Hải	5,341	6,624	151

Table 4: Demographics

5.1.7 Assumptions and bottlenecks

Based on the previous paragraphs, multiple assumptions can be made which will be used as preconditions for further on in the research. These assumptions have been noted below.

- Local markets are only supplied in the morning.
- Markets within the scope area will only be supplied by two or three-wheeled vehicles.
- In the morning small and medium size trucks leave the scope area to supply other morning markets.
- Uniformly spread over the day, medium and large-sized contracted trucks arrive and depart from the Đề Gi harbour to outside zones except for the western zone.
- In the evening full medium and large-sized trucks arrive in the Đề Gi harbour and depart in the morning when sold out.
- No two or three-wheeled vehicles supply fish outside the scope area.

From the made assumptions and the retrieved findings from the site analysis, multiple existing bottlenecks have been identified within the road network. Additionally, bottlenecks in vessel handling have been described, but these are outside the scope of the project.

In the current situation, DT633 poses the biggest bottleneck within the An Quang commune. In the future, a new bypass will be constructed to address this issue. This presents a detour, raising the question of whether cargo transporters from the harbour will use the bypass or take a shorter route via the existing DT633 through An Quang. Furthermore, only a commune bypass will be created. This bypass does not connect both sides to a similar size of the road, which would eliminate the current bottleneck but create a new bottleneck at the district border where the dual carriageway ends and a small provincial road continues.

Due to the traditional patterns of the fishing activities and the local markets, it becomes evident that there exists a notable contrast between the high-demand peak periods and the low-demand non-peak periods at the Đề Gi harbour. This variance in demand makes the road connections surrounding the harbour more susceptible to overloading during peak periods.

The tourism industry is developing, leading to increased transportation between the tourist areas within the scope area Phù Cát Airport, Quy Nhơn and adjacent districts with tourism zones. This will result in more traffic flows on the DT639 which will not directly pose problems. However, traffic between Phù Cát Airport and the northern seaside tourism developments may traverse provincial road DT633. The DT633 is a road with very limited capacity, leading to the creation of a bottleneck.

Looking further into the future, a broader prosperity among the population may pose another challenge. As prosperity rises in the area, there will likely be an increase in car ownership. While this is indicative of economic growth, it will also bring traffic-related problems. Currently, motorbikes, often carrying up to four people, are the predominant existing mode of transportation, representing just 0.3 PCU (Passenger Car Unit) (Tiêu Chuẩn Việt Nam 2005). As more individuals can afford cars, more space will be needed on the existing road network, as a car is equivalent to 1 PCU. Despite the potential of cars to transport more people at once compared to motorbikes, observations indicate that, on average, the number of people in a single car equals the number of people on a single motorbike. Consequently, this will lead to an increasing strain on all levels of the presently unprepared transport network.

5.2 Analysis and performance of network

The gained knowledge in the site analysis comes together to investigate and assess the transport network and subsequently have a basis model on the grounds of its performance. The selected model is the 4(+1)-step transport modelling approach which is in essence an extension of the conventional 4-step model that incorporates one extra step which is the indicated travel time period. This model normally uses a choice modelling framework by finding out the benefit associated with performing an activity at a certain destination and the specific time period as well as the route and mode choice. However, the first analysis to give more insight into the transport network system is to use a simple model and the philosophy that is built upon the more extended choice modelling approach of the 4(+1)-step model. The scheme of the model is depicted in figure 17. Typically the objective of the model is to find a balance in demand and supply by pinpointing the different travel choices that are made by the travellers, which in this case is mostly regarding the transportation of the goods, fish. The various travel choices entail mostly the questions, 'Where to?', 'What time?', 'What mode?', 'What route?'. By assessing the network with an aggregated approach, the method is suited for the desired initial purpose. However, this first evaluation doesn't capture heterogeneity in travel behaviour, which is of less importance in this stage without prior research done before.

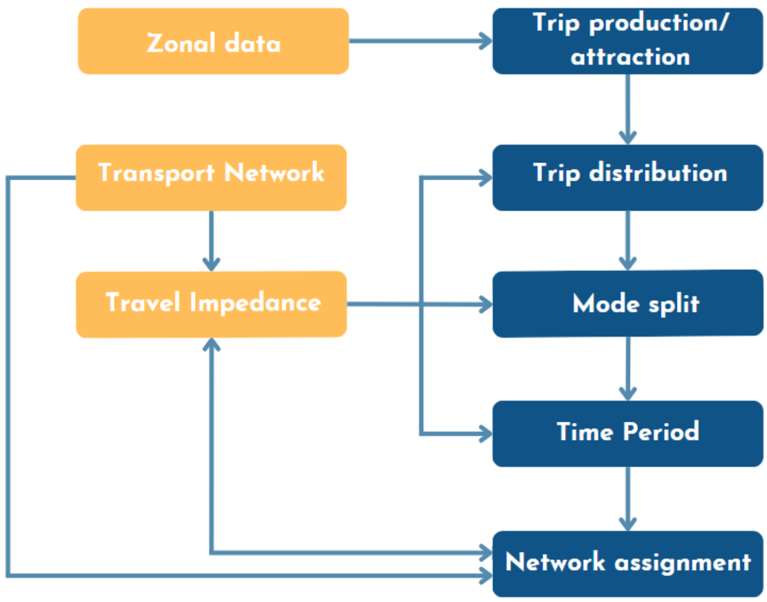


Figure 17: Visualization of the 4(+1)-step transport modelling (Cats 2022)

5.2.1 Step 1: Attraction and production

The primary interest lies in harbour-related induced trip purposes, specifically, those destined for local markets within the study area. Destinations beyond this scope are not considered in this analysis. The first step of the model concerns the trip generation, in this case, it is about the trips with the Đề Gi harbour as origin or destination for a single trip. Therefore, the study area is first split into sixteen zones for internal transportation based on the administrative commune distribution of the local government. The four external zones are established on the basis of external transport directions. To the northern and southern provinces via the QL1A (or the future CT01), to the western region of Bình Định and towards Quy Nhơn metropolitan area. Figure 18 visualizes the internal zones with locations of the local markets and four main external transportation directions from the Đề Gi harbour.

Figure 18: Visualization zones including local markets

While most communes are associated with a single market, exceptions exist, necessitating adjustments in the zoning method are needed. There are a few methods used to assign communal areas to a market. The first method is that zones lacking a market have been added to adjacent zones featuring a market. This is for example the case for Cát Thành which has been merged into the southern market of Cát Khánh. Another method that has been applied, is the merging of communal zones, which is applied in Phù Mỹ and Mỹ Quang. The opposite of this method is to split a commune with multiple markets which is done for example to Cát Minh. The last method is also applied to the last mentioned communal zone of Cát Minh, the smallest market has been discarded since the size of the market is too insignificant. All of these mentioned changes have influenced the zones that are used as input of the model. The changed zones are illustrated in figure 18, this includes the examples given above but also includes adjustments that are not mentioned that do comply with the given methods, while the original borders and markets of the communes are depicted in figure 5.

Traffic with destinations outside the defined scope area is categorized into four distinct groups: northbound nationwide, southbound nationwide, westbound intraprovincial, and Quy Nhơn metropolitan area bound traffic.

North and southbound traffic is presumed to follow either national highway QL1A or, in the future, motorway CT01 to reach the destination. Once traffic reaches the boundary of the defined scope area along these routes, no further assumptions are made. Notably, twelve kilometres south of the scope area, the QL1A intersects with a westbound national highway. In the northward direction, this is situated 80 kilometres from the scope area's border. Consequently, all longer-distance westbound traffic will be combined with the southbound traffic. Westbound intraprovincial traffic includes all traffic heading to the western part of the Phù Cát and Phù Mỹ districts and the southern part of the Hoài Ân district. These areas are only accessible via the provincial roads DT638 and DT634. Traffic bound for the Quy Nhơn metropolitan area consists of all traffic destined for Quy Nhơn markets, traffic to the in-development Nhơn Hội Economic Zone, Nhơn Hội Industrial Park and other industrial parks in the vicinity. It is worth mentioning that fish processing companies are present at both the Nhơn Hội Economic Zone and Nhơn Hội Industrial Park.

5.2.2 Step 2: Distribution

For the distribution between the internal and external zones, it is important that the total tonnage for all nodes and zones is known.

An absolute value for daily catch is not present, only a yearly tonnage. Based on interviewing multiple people at the Đề Gi Harbour, the fortnightly peak as described in subsection 5.1.2 is approximately three times the size of an ordinary day. During the three-month fishing season daily port calls are approximately double. These values are difficult to check due to a lack of data. Further research is advised but for this initial report, these values will be used.

The current catch of Đề Gi is 24,000 tonnes a year. The Quy Nhơn catch is 40,000 tonnes a year (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022). Due to the Quy Nhơn harbour reducing the fishing vessel capacity it is expected that a shift from Quy Nhơn fishing vessels to both more fishing vessels and more aquaculture in Đê Gi as well as Tam Quan which is described in section 2.3. Both fishing and aquacultural streams will be traversing through the Đề Gi harbour. Therefore half the tonnage of Quy Nhơn is expected to shift to Đề Gi harbour. This yields an expected yearly tonnage of 44 tons.

Both values together yield the daily catches. Due to the catch tonnage not being similar on different days table 5 shows the percentage and the absolute value for a peak day and an ordinary non-peak day.

		Fortnightly peak			
		Yes		No	
		Tonnes/day	% of year catch	Tonnes/day	% of year catch
Fishing Season	Yes	507	1.15	168	0.38)
	No	253	0.57	84	0.19

Table 5: Expected catch for different time periods

From the patterns described in subsection 5.1.2 a set precondition is that all two or three-wheeled vehicles will depart to a local market. Also, the condition is set that trucks are unable to deliver to these local markets.

From data collected by vehicle type counting, a division can be made between internal and external trips. Based on the vehicle type the tonnage can be calculated for all internal nodes together. The population is used to distribute overall trips and tonnage over the different internal nodes. For every node, the population is known from subsection 5.2.1. The fish sales to the local markets are sold for human consumption of the local markets customers which automatically suggests that the population of each market's catchment area may determine the fish consumption based on the assumption that only the closest market will be visited by residents. Therefore the ratio between node population and scope population will be used as the ratio for the freight to each node. Thus the amount of fish to the market is the total catch multiplied by the two and three-wheeler, truck ratio multiplied by the node population, and scope population ratio (figure 19).

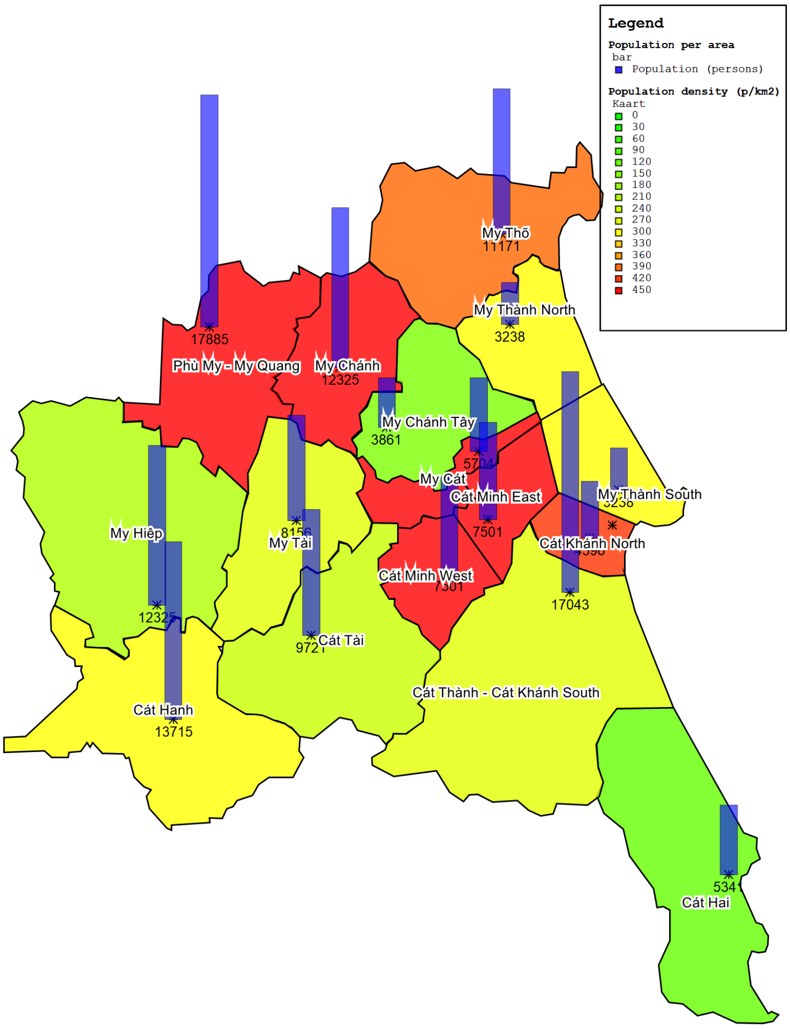


Figure 19: Population and population density

For the external zones, the licence plates indicate the district of the truck and therefore the corresponding external zone. Due to the mix between types of trucks to each zone differing per zone, the tonnage is calculated on the count of the truck types per zone. This yields both a transported tonnage capacity and a trip count per zone which can be set as a ratio to the total transported tonnage capacity including all modes resulting in the share of trips to each external zone and the share of tonnage to each external zone.

Only 29.8% of the catch tonnage stays within the scope area while internal trips account for 89.8% of all trips. Therefore depending on which criteria are being used totally different results can be expected. Both trips and tonnage are on display in table 6.

	Nodes and zones	Transportation to nodes and zones			
		Trips	Tonnage		
		[%]	[%]	Peak day [Ton]	Low day [Ton]
Intern	Mỹ Thọ	6.99	2.33	11.8	1.95
	Mỹ Thành North	2.03	0.67	3.4	0.57
	Mỹ Thành South	2.03	0.67	3.4	0.57
	Mỹ Chánh Tây	2.21	0.80	4.1	0.68
	Mỹ Chánh	7.62	2.57	13.	2.16
	Phù Mỹ - Mỹ Quang	11.2	3.72	18.9	3.13
	Mỹ Hiệp	7.72	2.57	13.0	2.16
	Mỹ Tài	5.11	1.70	8.6	1.43
	Mỹ Cát	3.57	1.19	6.0	1.0
	Cát Minh East	4.70	1.56	7.9	1.3
	Cát Minh West	4.70	1.56	7.9	1.3
	Cát Tài	6.09	2.02	10.3	1.7
	Cát Hanh	8.59	2.86	14.5	2.4
	Cát Khánh North	2.75	0.92	4.6	0.77
	Cát Thành - Cát Khánh	10.67	3.552	18.0	2.98
	Cát Hải	3.34	1.11	5.6	0.93
Extern	Quy Nhơn	4.85	31.99	162.2	26.87
	Bình Định West	2.77	3.55	18.0	2.99
	QL1A North	1.39	15.99	81.1	13.44
	QL1A South	1.39	18.66	94.6	15.68

Table 6: Daily transportation to each node

5.2.3 Step 3: Mode choice

The next step in the conventional four-step transportation model after the trip distribution is regarding the mode choice. The mode choice can utilize a range of performance variables a trip-maker can opt for when reaching the destination. Depending on the benefits of each mode, the user chooses how to travel and in this specific case how to transport goods. This step in the model provides and determines the share of each transportation mode from the trips generated. With the philosophy of the model and the knowledge that goods are transported. The most commonly used process involves a comparison of the disutility and utility of travelling between two points with different modes. Factors that are of importance are mainly, travel time, costs and the convenience of a mode for the specified trip. Depending on the distance, it could be possible that a vehicle with more capacity to carry goods is desired. To model further, the characteristics of each mode that is considered are depicted in figure 9. In the theory, a mode bias factor is often used in this step to determine the benefit of using a certain mode for the chosen trip, namely

				Percentage of tonnes transported by mode					
	Nodes	Distance	Share	Bike	Trike	Tuk-Tuk	S Truck	M Truck	L Truck
Intern	Mỹ Thọ	14	2.32	1	0	0	0	0	0
	Mỹ Thành North	8	0.67	1	0	0	0	0	0
	Mỹ Thành South	2.5	0.67	1	0	0	0	0	0
	Mỹ Chánh Tây	12	0.80	1	0	0	0	0	0
	Mỹ Chánh	16	2.57	1	0	0	0	0	0
	Phù Mỹ - Mỹ Quang	20	3.72	0.603	0.397	0	0	0	0
	Mỹ Hiệp	23	2.57	0	0	1	0	0	0
	Mỹ Tài	16	1.70	1	0	0	0	0	0
	Mỹ Cát	8.3	1.19	1	0	0	0	0	0
	Cát Minh East	6.4	1.56	1	0	0	0	0	0
	Cát Minh West	8	1.56	1	0	0	0	0	0
	Cát Tài	15.1	2.02	1	0	0	0	0	0
	Cát Hanh	21.8	2.86	0	0.603	0.397	0	0	0
	Cát Khánh North	0.6	0.92	1	0	0	0	0	0
	Cát Thành - Cát Khánh	4.6	3.55	1	0	0	0	0	0
	Cát Hải	14.4	1.11	1	0	0	0	0	0
Extern	Quy Nhơn		31.99	0	0	0	0.0556	0.6944	0.25
	Bình Định West		3.55	0	0	0	1	0	0
	QL1A North		15.99	0	0	0	0	0	1
	QL1A South		18.66	0	0	0	0.0952	0.4761	0.4287

Table 7: Vehicle share distribution per zone

the alternative specific constant (ASC). However, due to the simplicity of this initial model and theoretical approach, no quantitative numbers are used for this constant yet it is noted for further development. Nevertheless, in this initial model, the assumption is made based on the distance. For larger distances, it is expected a larger vehicle is used due to the impossibility of travelling many times back and forth while for relatively short trips smaller vehicle types are preferred.

In paragraph 5.1.2.2 the mix of vehicles exiting the harbour terrain is described. The percentage of the largest vehicles is distributed over the longest trips. In table 7 the share of modes for each node is visual. For the external trips, the license plate count conducted reveals the distribution of vehicle types per zone.

5.2.4 Step: Time

As described in subsection 5.1.2, a morning peak is present with trips to local markets. this peak does start around 4.30h in the morning and diminishes around 6.30h. This peak is not evenly spread over two hours. Earlier in the morning the traffic volume starts high and slowly vanishes. In the early morning, it is still possible to reach further markets while over the duration of these two hours less markets are reachable on time. During these two hours, all goods to local markets within the scope area will be distributed. Therefore a peak hour will consist of more than half the daily inner scope area goods. For this project with an educated guess the peak hour will be set to 55% of the daily intern tonnage value.

The morning peak can also be noted with trucks outside the scope area. However, these peaks are less noticeable. For the western districts, no processing facilities are present and thus this suggests a similar peak pattern of the interzonal nodes. From Quy Nhơn a peak can be noticed with trucks arriving in the evening around 21h and departing around 7h. However, for Quy Nhơn the load is much more uniformly distributed over the day. The trips will be equally distributed over a timespan between 4h and 24h with the peak hour double of other hours. Therefore the peak hour is 9.5% of the daily Quy Nhơn Tonnage.

For the northern and southern external zones, there has not been a peak observed during the site visit while interviewing local craftsmen concluded similarly. Therefore the peak for both northern and southern bound trucks will be set as if all trips are uniformly distributed between 4h and 24h. Therefore the peak hour is set to 5% of the daily catch to these zones.

To summarize the percentages:

- Interzonal: 55%
- West Bính Định: 55%
- Quy Nhơn: 9.5%
- Northern zone: 5%
- Southern zone: 5%

5.2.5 Step 4: Traffic assignment

Step 4 in the conventional 4-step transport modelling approach is about the traffic assignment and concerns the selecting of the routes. This is in order to determine and evaluate the facility needs which is based on the understanding of the number of travellers on each route and thus the links of the network. Therefore, determining the specific path of the trips between origin and destination is key which is normally done by using the utility of choosing the specific route. The mentioned utility is most often based on distance, travel time and costs. In the case of the Đề Gi harbour, travel time is the most relevant for the utility of the route.

For the allocation of the traffic in the network, the All-or-Nothing (AoN) is chosen as the most appropriate assignment for the research area, with two corresponding assumptions. It can be assumed that all traffic between an OD-pair (Origin-Destination Pair) is assigned to just one route, namely the shortest route based on travel time. Furthermore, the travelling time of all paths is assumed to be constant and does not change with the intensity of roads, based on the result of the field observation. The main calculation step of this assignment is to use an algorithm to determine the shortest path and then assign all traffic flows of all OD-pairs to the shortest path accordingly (Pel 2023). This leads to a system optimisation problem as follows:

$$\min_{T_{ijr}} Z = \sum_i \sum_j \sum_r t_{ijr} \times T_{ijr} \tag{2}$$

Subject to:

$$\sum_r T_{ijr} = T_{ij} \tag{3}$$

$$T_{ijr} \geq 0 \tag{4}$$

In this optimisation problem, Z is the impedance or the total generalized travel time of the whole network, T_{ijr} is the number of OD trips from origin i to destination j taking route r and t_{ijr} is the travel time on route r from i to j. Depending on the travel direction, the Đề Gi harbour can be both the origin and destination of an OD trip. The corresponding travel times and therefore the travel impedance for the OD-pairs are given in table 8.

	Zone	Travel time [min]
Internal	Mỹ Thọ	15
	Mỹ Thành North	15
	Mỹ Thành South	6
	Mỹ Chánh Tây	13
	Mỹ Chánh	19
	Phù Mỹ - Mỹ Quang	23
	Mỹ Hiệp	28
	Mỹ Tài	23
	Mỹ Cát	10
	Cát Minh East	8
	Cát Minh West	12
	Cát Tài	18
	Cát Hanh	25
	Cát Khánh North	2
	Cát Thành - Cát Khánh South	7
	Cát Hải	14
External	Quy Nhơn	22
	Bình Định West	27
	QL1A North	31
	QL1A South	26

Table 8: Impedance of the route

This AoN traffic assignment is then done for peak hours while forecasts of trips are done on a daily basis. To determine if the connection is congested, the allocated trip volume is compared to the link's capacity. If there is a certain connection that becomes congested, the whole process of traffic assignment can be repeated a few times based on the utility function such that an equilibrium can be reached in the travel demand and supply. In the exploration of the road network of Đề Gi and therefore the traffic assignment, this is the initial look that is given to the intensity of each link in the scope area, compared to the corresponding capacity.

5.3 Conclusion

To be able to answer the main research question concerning the current performance of the Đề Gi port and how engineering methods can be used by the development of the Đề Gi area, an analysis of the network capacity of the Đề Gi area is performed using the results of the field observation in considerations of the future development visions for Đề Gi area. The result of this analysis is also the answer to the first sub-question:

> *'How will the current logistic service network perform in the future vision as foreseen by the responsible authorities and how to verify it with an engineering responsible approach?'*

Network capacity's performance
For the assessment of the current network capacity performance, various aspects are analysed. The pattern of the Đề Gi harbour, (goods)transport vehicles, the traffic network, the land use and the demography within the study area. This results in various potential bottlenecks in the transport network of the Đề Gi area:

- Several connections between the local fish markets and the harbour have very poor transport infrastructure. This leads to a low effectiveness of local fish transportation.
- Due to the lack of traffic information and conditional driver behaviour, rat-running occurred in several narrow country and urban roads around the Đề Gi harbour. This leads to inefficient traffic distribution in the network and ineffective use of the intended infrastructure.
- From the analysis of the harbour patterns, it can be seen that there is a significant difference between the peak and the non-peak moments in the traffic demand for the Đề Gi harbour due to the fishing patterns. As a consequence of this difference, the road connections around the harbour are likely to be overloaded during the peak moments.
- Due to the new network infrastructure, there are possibilities for capacity drops at the connections of the new and the existing roads. This will result in the overloading of several connections in the existing traffic network.
- In the development plans of the Đề Gi area, the local authority has great ambitions for the growth of urbanisation and tourism, undoubtedly this will also lead to an increase in traffic intensity in the area. This increase may form a threat to the low-capacity connections of the traffic infrastructure network of the area.

Traffic modelling
It is apparent that the most bottlenecks in the current transport network concern the intensity/-capacity issues, which require improvements in the traffic infrastructure of the network. However, this assessment is based only on a qualitative analysis, for more reliable and consistent results a quantitative engineering approach is necessary to verify the drawn bottlenecks.

Therefore, a 4(+1) step modelling should be used for the simulation and mapping of the traffic demand distribution over the transport network of the area. In this model, various traffic data is the input of the model. These are the zonal data for internal and external zones, the traffic demand per OD-pair, the distribution of the modal split for the fish transport from the Đề Gi harbour and finally the travel time per travelled route as the impedance of traffic assignment.

For the final traffic assignment, the All-or-Nothing traffic assignment is chosen to assign the traffic demand over the given transportation network of the area. This traffic assignment choice has been made based on two assumptions relating to the uniqueness of the route between an OD-pair and the constancy of the impedance of each route. Therefore an optimisation problem is developed with the travel time in minutes as impedance in the assignment.

6 Nautical Accessibility

This chapter serves the following research question:

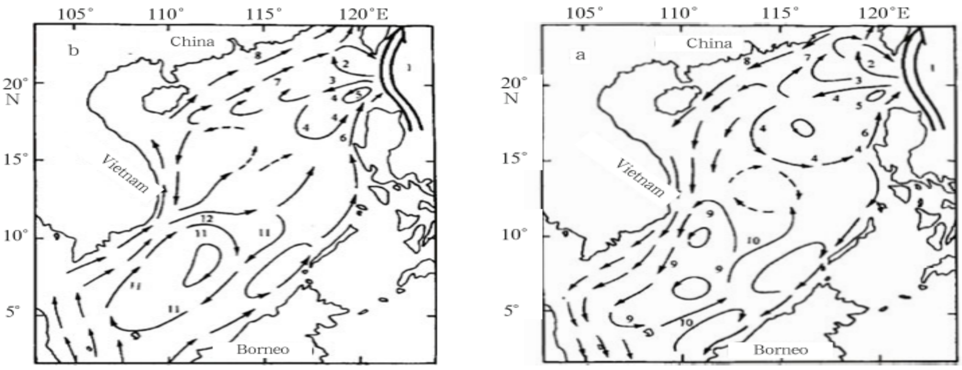
> *'How to examine the accessibility of the port and storm shelter in the KND project, while ensuring a safe, robust, durable and effective system?'*

In this chapter, the coastal system is described from a general perspective to understand how the global system influences Vietnam (section 6.1). Subsequently, the focus is concentrated on the Bình Định Province and more specifically the Đề Gi area (section 6.2). Topics on climate, hydrodynamics and morphological features are discussed to create an understanding of the local conditions. Furthermore, attention is being paid to the nautical access channel that connects the sea with the lagoon (section 6.3). Since such an entree is highly necessary for reaching accessibility to the Đề Gi port and storm shelter, section 6.4 focuses on this mapping. Results regarding this accessibility topic are discussed in subsection 6.4.4.

6.1 Coastal Systems Vietnam

The 3260 kilometres long coastline of Vietnam is bordered by the East Sea (Zhaoyin et al. 2023). Because the coastline of Vietnam is protected by an island arc of Indonesia, Malaysia and the Philippines and is located away from tectonic plates, the coastline can be classified as a marginal sea coast. Marginal sea coasts typically have a broad continental shelf and shallow seas. This is mainly visible in southern and northern Vietnam. The width of the shelf has an effect on the hydrodynamic conditions. A broad shelf, which generally has low gradients and low wave energy coasts, promotes the development of sedimentary features. Large deltas, like the Mekong Delta in Vietnam, have been shaped on marginal coasts with broad shelves (Bosboom and Stive 2023). The shelf of central Vietnam is significantly narrower (approximately a length of 40 kilometres) leading to a steeper slope, smaller storm surges, higher wave height and smaller tidal amplitudes (Szczuciński et al. 2008). The continental shelf of Vietnam consists mostly of sand and mud. The coastal plains of marginal sea coasts can be very diverse. The landscapes are low-laying or hilly and the form can be determined by local processes (Bosboom and Stive 2023).

The East Sea, the largest marginal sea in the world, encounters a strong current flowing along its western boundary. Due to the fact that Vietnam experiences a tropical monsoon climate, the average flow field is seasonal, which is characterized by the importance of the two main seasons, summer and winter. During summer (May - September), the air pressure is lower on land than at sea. A South West monsoon (SW monsoon) develops a wind pattern that blows from sea to land creating a current shown in figure 20a. In winter (October - April), the air pressure at sea is lower than on land, leading to a North East monsoon (NE monsoon) creating a current field shown in figure 20b. Mapping the seasonally average flow fields of the East Sea can help to comprehend the behaviour and possible changes of the coastline further in this research.



(a) Summer **(b)** Winter

Figure 20: Current patterns East Sea (Fang et al. 2012)

Under the influence of the NE monsoon, the highest waves occur in winter. This is because the distance over which waves can develop is greater during the NE monsoon than during the SW monsoon. The prevailing wind direction during the SW monsoon is southeast and because of the island arch, the distance over which waves can develop is small. A typical bottom profile for a monsoon climate is a relatively narrow sandy beach with a steep slope found mainly in central Vietnam (Bosboom and Stive 2023). The great majority of storms hit this region of Vietnam (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

Along with the East Sea's seasonal average flow fields, tides also have an impact on the coastal geological processes along the Vietnamese coastline. The world's large continental land masses generate a variety of tidal characters. The form factor F is used to determine the tidal character and the importance of diurnal versus semi-diurnal components. Equation 5 calculates the form factor (Bosboom and Stive 2023).

$$F = \frac{(K_1 + O_1)}{(M_2 + S_2)} \tag{5}$$

Where:
K_1 is the amplitude of the lunar-solar declinational diurnal (m)
O_1 is the amplitude of the principal lunar diurnal (m)
M_2 is the amplitude of the principal lunar semi-diurnal (m)
S_2 is the amplitude of the principal solar semi-diurnal (m)

Vietnam experiences mainly a mixed diurnal tide meaning the tidal cycle consists of semi-diurnal and diurnal tides, with significant variations in the height of succeeding high tides or low tides throughout the cycle. The form factor of this tidal cycle is between 1.5 and 3. An example of a mixed mainly diurnal tide near a Vietnamese city is shown in figure 21 (Bosboom and Stive 2023).

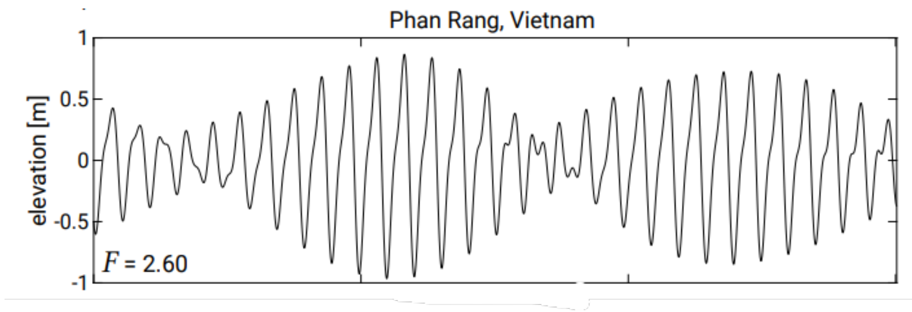


Figure 21: Mixed mainly diurnal tide Phan Rang, Vietnam (Bosboom and Stive 2023).

Because of the tropical monsoon climate in Vietnam and the influence of the tide, the interaction between sea, river and land is very strong. Along the coastline of Vietnam, over 130 estuaries and two large deltas (Red River delta & Mekong delta) can be found, many of which serve as important centres for international trade and transit. Unfortunately, a lot of regulation work and dredging must be done to stabilize the access channel which limits the economic development locally, regionally and nationally (Zhaoyin et al. 2023). Estuaries can be classified by its shape which depends on where the estuary is situated: river-, wave- or tide-dominated area. In Vietnam, mainly tide-dominated estuaries are found with a wave-dominated ebb delta (Bosboom and Stive 2023). On the margins of estuaries and other basins, mangrove forests are able to grow and these forests play a major part in the socio-economic development of Vietnam. Among their many benefits are coastal protection, medicine, carbon storage, food and building materials (Veettil et al. 2019). Mangroves are mostly found on low-latitude coasts with tropical or subtropical climate zones (Bosboom and Stive 2023). Unfortunately, a lot of Vietnamese mangrove forests have been lost in recent decades. Mostly because of the herbicides during the American War (Veettil et al. 2019).

6.2 Coastal system of the Đề Gi area

Zooming in on the project area, the characteristics of the coastal system of the Đề Gi area become more concrete and coherent. For a better understanding of coastal-related topics as Climate (6.2.1), Hydrodynamics (6.2.2) and Morphodynamics (6.2.3) this section provides an in-depth description of the 'local' coastal system.

Figure 22: Đề Gi estuary area.

6.2.1 Climate

The climate influences hydrodynamic conditions and is therefore meaningful to understand. Important meteorological aspects in the region around the Đề Gi area are precipitation, sunshine, temperature, humidity, wind, storms and climate change. These aspects are based on a climate report published by the Department of Science and Technology Bình Định province (Department of Science and Technology Binh Dinh province 2005).

Precipitation
The number of days per year with rain in the Phù Cát district is 75, which is lower than the approximate 100-day average in the whole Bình Định province. This is due to the higher rainfall in the mountainous areas elsewhere in the province. The amount of rainfall strongly correlates to the dry and rainy seasons, since the frequency of rain seasons and rainfall is approximately the same. The average annual rainfall in Bình Định is about 1500 mm, which is slightly higher than the 1300 mm rainfall in the Phù Cát district. 75% of the rainfall is experienced in the wet season, starting in September when the NE monsoons are prevailing. Of all meteorologic properties, the precipitation statistics are the most volatile.

Sunshine
The Bình Định province is located at the 14th parallel north latitude, which gives it a tropical solar regime. Being close to the equator, the length of the day is rather stable and long, therefore the solar energy received in the province is quite ample. The annual solar radiation is roughly

140-150 kcal/cm^2, which is 10 % more than the country's capital Hồ Chí Minh City. The received solar radiation is the highest in the low-clouded April. Clouded December with a relatively low sun angle receives the least sun.

Temperature
The average annual temperature is around 27° Celsius with a deviation of the average in the range of 24° to 31°. The lowest temperatures appear at the start of the year in January. The highest temperatures are experienced in the northern hemisphere summer. On average the temperature only drops below 20° for a maximum of five days, only during the winter monsoon. In the summer period, there are up to 55 days of temperatures above 30°, in combination with low precipitation levels drought is experienced.

Humidity
The average relative humidity in the region is around 80%, which may change up to 30% depending on the time of the day and the weather conditions. The humidity variation throughout the year is limited. A relative humidity below 50% is only experienced for a maximum of 25 days annually.

Wind
During the winter monsoon, the northeastern wind is prevailing. In the summer monsoon, the wind direction is opposite, coming from west/southwest. The average annual wind speed is roughly 1.6 m/s. Where wind speeds below 1 m/s are the most common, speeds above 10 m/s are only measured 1% of the time, mostly during storms in combination with other extreme weather phenomena. The coastal area of Đề Gi experiences the highest winds in the winter monsoon, when wind is approaching from sea. In the summer period, the coast is sheltered from the southeastern wind by mountain ranges.

Storm
Southeast Asia experiences counterclockwise rotating cyclones, which categorize as either tropical depressions or storms of which storms generate higher cyclone centre wind speeds from 8 beaufort and up, whereas a tropical depression has wind speeds of 6-7 beaufort. The strong winds and accompanying intense rain are dangerous for people and the economy, considering the damage to people and property. However, in a low-raining season, a tropical depression is sometimes appreciated, since it supplies fresh water to be used for agriculture and nourishment. Storms and tropical depressions can have a total rainfall of 200-300 mm and normally last 2-3 days, however, the buildup to a storm may also be categorized as a tropical depression, thus extending the time of intense weather. On average twelve tropical storms and tropical depressions are observed in the East Sea annually. The cyclones are either generated in the East Sea or move in from the Western Pacific. Not all of these storms affect the Vietnam mainland. In general, roughly 5-7 storms have a considerable impact on the country, foremost arising in the storm season between March and December. One of these storms impacts the Bình Định province every year, where one in two years such a storm directly lands in the province (Công Ty CP Thiết Kế và XDCT Tường Sinh, Viện Đào Tạo và Khoa Học Ứng Dụng Miền Trung January 2022). The table below gives the number of days with smaller and larger thunderstorms per month and the yearly average:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0.1	0.0	0.3	1.7	6.3	4.6	3.0	3.9	8.0	4.9	0.9	0.1	33.8

Table 9: Annual and monthly average storm days

Climate change
In 2022 the Intergovernmental Panel on Climate Change published the report "Climate Change 2022: Impact, Adaptation and Vulnerability". According to this report, Vietnam is in the group of "Most Vulnerable Countries" to climate change (Trung 2023). Therefore, it is "the most pressing threat facing Vietnam over the next couple of decades", the Climate Change and Environment Unit at the UN Development Programme's Vietnam (UNDP 2018). The World Bank Group sketched a climate risk profile for Vietnam in collaboration with the Asian Development Bank back in 2021. This report describes the expected change in the climate and the potential effects.

The temperature increase of 1 - 3.5°C in Vietnam is in line with the global expected temperature increase by 2100. However, the intensity of the extremes tends to increase more than the average temperature. Extremes can be categorized in: (1) tropical depressions and typhoons, (2) monsoons and extremes (3) and damaging cold, heat waves and drought.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has suggested that storm intensity is likely to increase by 2 - 11 %. Also, storm rainfall is likely to increase by about 20 % in the 21st century. However, the number of tropical depressions and typhoons is predicted not to change significantly. Weaker and more moderate typhoons are therefore expected to decrease, whereas the number of strong typhoons is likely to increase. The coastal area of Đà Nẵng to Bình Định recorded the highest observed storm surge of 180 centimetres, however, a rise storm surge of 230 cm might occur in the future (Ministry Of Natural Resources And Environment 2016). So, the occurrence, intensity and impact of cyclones are expected to change, but at the moment it is poorly understood.

Furthermore, the IPCC expects that the summer monsoon will lengthen; models show it will start earlier and end later. Precipitation prediction at this moment is very uncertain due to the lack of proper models, but there is research that claims that the distribution of precipitation will change over the country (World Bank Group and Asian Development Bank 2021). The IPCC models also show an increase in the number of hot days (>35°C), with the most extreme duration of over fourty days at the South Central Coast and over fifty days by the end of the century. In conjunction with this, it is likely that drought on the South Central Coast will be more severe due to the decrease in rainfall in the dry season.

Aside from extreme climate conditions, the mean sea level (MSL) rise in Vietnam is likely higher than the global MSL rise. Scenarios based on the Fifth Assessment Report of IPCC indicate an increase of about 73 centimetres in 2100 near the Đề Gi area. Note that this sea level rise is based on scenario where emissions continue to rise rapidly (RCP8.5 Scenario), see figure 23.

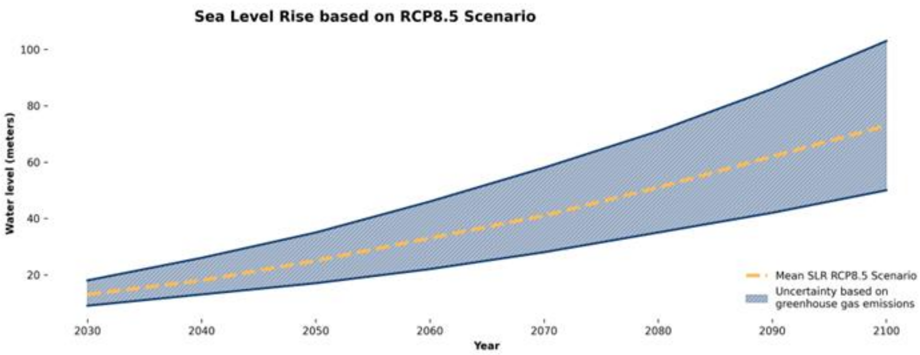


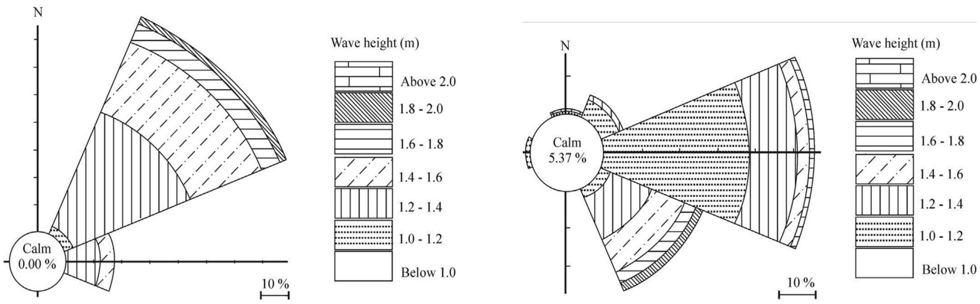
Figure 23: Sea Level Rise based on RCP8.5 Scenario

Generally speaking, Vietnam faces high disaster risk levels in multiple aspects. But since Vietnam is an extremely vulnerable country when it comes to sea-level rise, the main issue is the increased risk of flooding for low-lying parts of the country (Red River Delta & Mekong Delta), putting 6-12 million people at risk by 2070-2100. Furthermore, climate change is likely to affect agriculture, which is at the moment the basis of the economic position of the country. For the fishing industry specifically, this relates to changing fishing yield due to changes in seawater temperature and acidity. Another risk is heat stress in urban areas, which has a mainly negative impact on people's well-being and functioning (World Bank Group and Asian Development Bank 2021).

6.2.2 Hydrodynamics

Climate conditions enforce hydrodynamics. To better comprehend the forcing impact on the coastal system topics on wave conditions, tidal conditions and flow current are described.

Wave conditions
As already mentioned in section 6.1, the shelf of central Vietnam is narrower and this generally indicates that the coastal area has relatively deep water close to the shore because of a steep beach slope. Because of the relatively deep water close to the shore, wind waves start shoaling in a later phase, since there is no sea-bottom interfering and the waves will not be dampen-out. This ensures a relatively high wave energy climate. The wave climate in the Đề Gi area can be distinguished in a summer and winter period (see section 6.1). During winter, the northeastern wind is prevailing while during summer the southeastern wind is prevailing. Figure 24 shows an overview of the wind and wave direction, combined with information on wave height.



(a) Winter, October 2012 **(b)** Summer, June 2013

Figure 24: Wave rose at the Đề Gi estuary (Duc, Tung, et al. 2019)

Using an Airborne Warning and Control System (AWACS), this wave data was gathered. The winter measuring period runs from September 29 to October 5, 2012, and the summer measurement period runs from June 3 to June 10, 2013. Table 10 displays the average wave height, wave period, and dominant wave direction (Duc, Tung, et al. 2019).

	Winter, October 2012	Summer, June 2013
Average wave height (m)	1.4	0.32
Average wave period (s)	9.38	6.15
Dominant wave direction	61.7° (NE)	111.2° (SE)

Table 10: Wave characteristics Đề Gi estuary (Duc, Tung, et al. 2019)

The two wind roses, figure 24, show the change in wave characteristics between the two different monsoon seasons. The highest wave height occurs during the NE monsoon. These wave heights, according to Duc et al., result in high wave energy and wave impact near the coast, which trigger significant morphological changes (Duc, Anh, et al. n.d.).

The process of wave breaking can vary: surging, collapsing, plunging and spilling. The Iribarren parameter defines the breaking processes and can be calculated using the following equation (Bosboom and Stive 2023):

$$\xi = \frac{tan(\alpha)}{\sqrt{H_0/L_0}} \tag{6}$$

Where:
$tan(\alpha)$ is the steepness of the beach
L_0 is the wavelength in deep water in metre
H_0 is the wave height in metre

The wavelength in deep water can be calculated using equation 7.

$$L_0 = \frac{9.81 * T^2}{2 * \pi} \tag{7}$$

Where:
T is the wave period in seconds

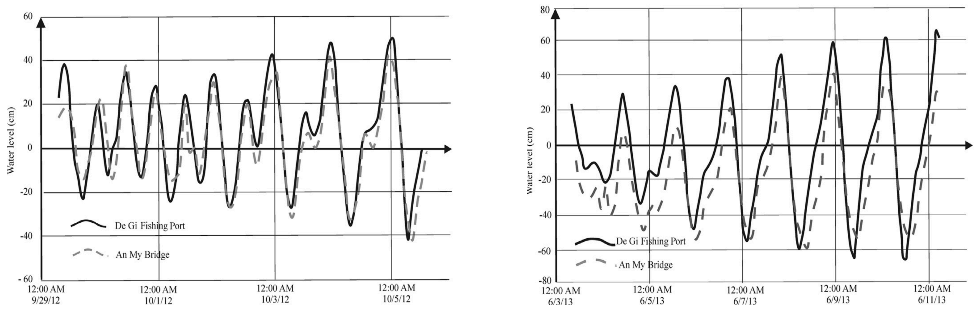
Using the wave height and wave period of table 10, the Iribarren parameter of the coast of the Đề Gi estuary can be calculated, see table 11.

	Winter, October 2012	**Summer, June 2013**
L_0 (m)	137	55
ξ (-)	1	1.3

Table 11: Iribarren parameter Đề Gi estuary

An Iribarren parameter between 0.5 and 3.3 can be defined as plunging breakers (Bosboom and Stive 2023). This breaker type is also observed during the field observations appendix D.

Tidal conditions
Often, a narrow continental shelf is related to a lower tidal range. In deep water, tidal waves have less ability to shoal. Also, (storm)surge levels are small for a similar reason. Water level data shown in figure 25a, show that the tidal range in winter is about 1.0m, between the extremes of maximum +0.54m and minimum -0.42m. Measurements during the summer in figure 25b show a tidal range of about 1.33m, the extremes hold a maximum of +0.64m and a minimum of -0.69m. Unfortunately, not much data on water levels is available in this area, nor in nearby cities. Live tidal predictions for the coming month (Tide forecast, 2023) show similar results as in figure 25. However, this characterizes a micro tidal regime, since the mean spring tidal range is below 2m. With the form factor described in 6.1 the tidal character can be determined.



(a) Winter, October 2012 **(b)** Summer, June 2013

Figure 25: Water level measurements (Duc, Tung, et al. 2019)

For calculating the form factor using equation 5, the tidal constituents of Tam Quan are used. Tam Quan is situated near the Đề Gi estuary and demonstrates comparable hydrodynamic conditions. Based on the tidal constituents of table 12, a form factor of 2.0 is calculated using equation 5. This is consistent with the results of the tidal range of figure 25 resulting in a mixed, mainly diurnal tidal character as described in section 6.1.

Tidal Constituents	**Name**	**Equilibrium Amplitude [m]**
Diurnal		
Lunar-solar declinational	K1	0.30
Principal lunar	O1	0.30
Semi-Diurnal		
Principal lunar	M2	0.20
Principal solar	S2	0.10

Table 12: Tidal Constituents Tam Quan (Trinh et al. 2015)

The relationship between mean tidal range and wave height results in a relative tidal range of mixed energy (wave-dominated) character.

The standardized water levels used for design are indicated in table 13.

Water level (VN)	**Water level (EN)**	**Elevation w.r.t. Chart Datum (m)**
MNTK	Design Water Level (DWL)	+ 1.06
MNTC	Mean High Water (MHW)	+ 0.77
MNTB	Mean Sea Level (MSL)	+ 0.10
MNTT	Mean Low Water (MLW)	- 0.70

Table 13: Water levels w.r.t. Chart Datum (CD) Hondau based on document TVCN9901-2014 and (Ngoc et al. 2022)

For assessment purposes, it is interesting to see statistical data about water levels, because the water levels above are averaged water levels. The tidal character is mixed, mainly diurnal, which means there are differences in the tidal range and thus water level. The following graph shows the

99% confidence interval of the water level in Đề Gi represented as a tidal cycle. The graph is a fitted function to statistical water level data in Đề Gi, converted from measurement data in Quy Nhơn between 1977 and 2004 (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

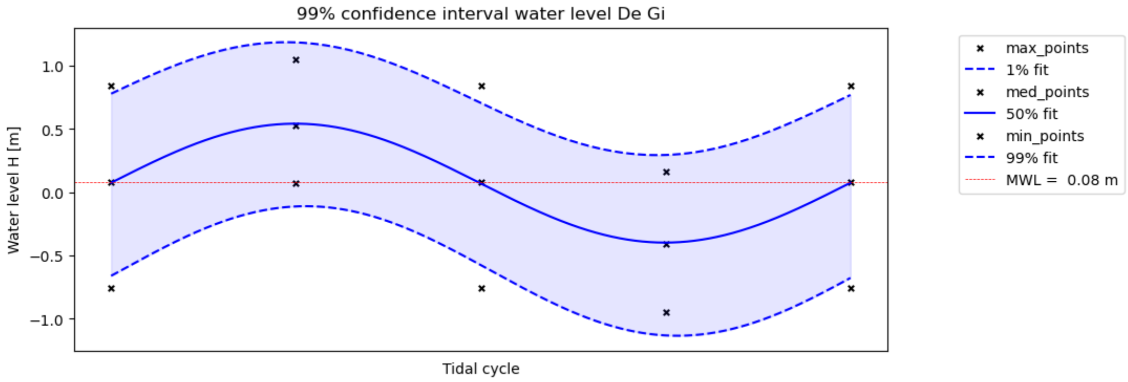


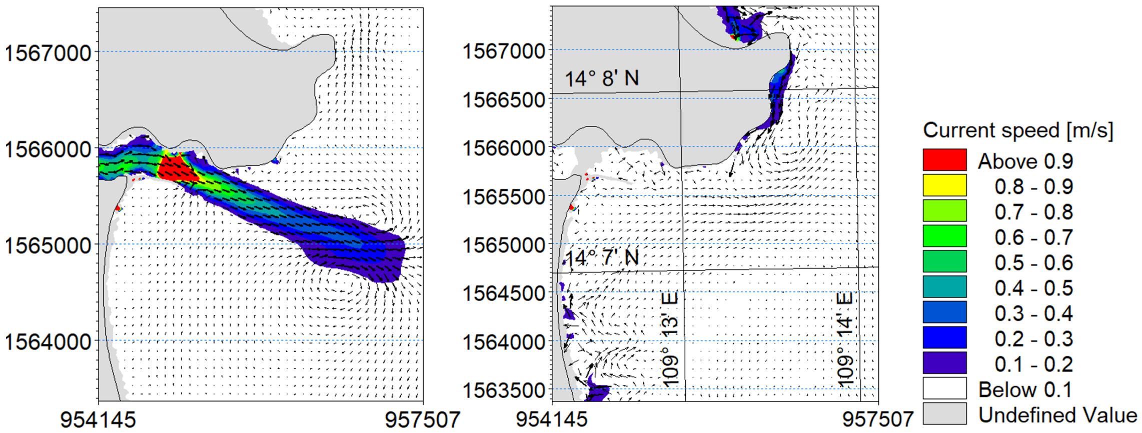
Figure 26: 99% confidence interval water level Đề Gi

Current

Currents occur due to the influence of waves, winds, tides and rivers. As mentioned before, the river flow is minimal. It accounts for a water collection area of only 1000 km^2. According to Duc et al, the average impact of the river on the flow in the Đề Gi estuary is 3.43% during high tide flow and 2.7% during low tide flow (Duc, Anh, et al. n.d.). Therefore, this impact is marked as insignificant during non-flood periods. So, the flow climate in the estuary is dominated by the ocean processes of wind waves and tides.

Larger scale flow circulations in the Đề Gi area differ seasonally. Central Vietnam's climate is influenced by a NE monsoon in winter and a SW monsoon in summer as mentioned in section 6.1, see figure 20. The figure shows the flow directions and seasonal characters. The actual flow circulation in the Đề Gi area can be seen as a summation of the tide and seasonal-flow hydrodynamic conditions. Various papers calculated the flow magnitude and direction by using the MIKE21 simulation model (Duc, Anh, et al. n.d.).

A simulation of only tidal influence at the Đề Gi area is visualized in figure 27a. The figure shows the low tide condition which turns out to have the highest velocities (Duc, Anh, et al. n.d.). Velocities greater than 0.9 m/s near the beginning of the channel can be obtained, gradually decreasing when flowing out into the ocean in an east-southeast direction. Additionally, eddy formation is witnessed, due to return current. Also, just south of the jetty, a small circulation occurs. Figure 27b shows that the tidal influence is minimal when the lagoon entrance is completely closed. This indicates a strong relationship between the lagoon and the ocean due to the estuary.

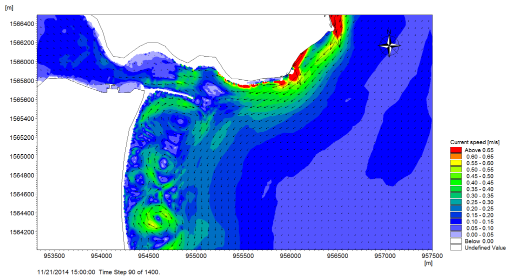


(a) Flow affected by low tide **(b)** Flow of tide and closed lagoon **(c)** Flow Legend

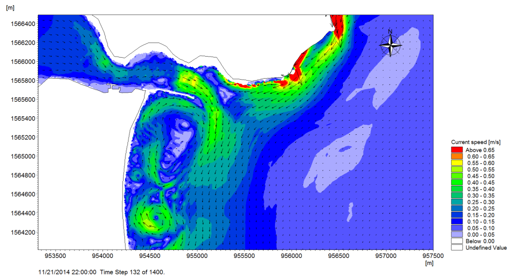
Figure 27: Flow circulation by tides (Ngoc et al. 2022)

Besides tidal effects, seasonality also interferes and contributes strongly to the overall current flow. Paragraph Wave conditions state that the NE monsoon has the largest wave energy and impact. The winter period differs monthly in a wind-wave direction from north to southeast, with the climax in December where the highest waves from the northeast direction are observed at about 1 - 2 metres near the headland (Duc, Anh, et al. n.d.). The winter months also have the most occurrence of storms, see paragraph Storm. With that in mind, the strongest flow circulations due to hydrodynamic processes are expected to be found during the NE monsoon.

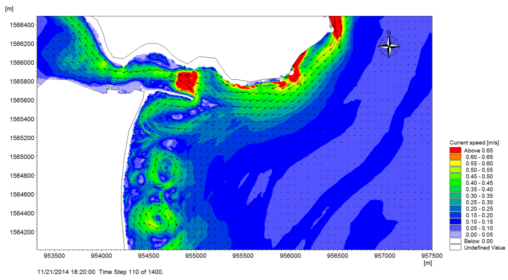
Figure 28 shows a modulation of the flow circulation containing NE monsoon hydrodynamic conditions during high and low tides. What stands out is the different eddy developments along the southern coastline. In all simulation scenarios, the eddy locations and directions follow a similar pattern; near the coast smaller eddies are formed and near the breakwater, a constant flow pattern moves along the breakwater in the direction of the channel inlet. Besides the smaller eddies, a larger circulation is visible during low tide, especially with high-velocity conditions. The general flow direction along the southern coast is northwards. Aside from these current formations, another noticeable observation is the dynamic equilibrium flow around the headland experiencing an independent flow direction from north to south. During low tide, the outflow of the current around the headland meets the outflow of the estuary near the inlet of the channel.



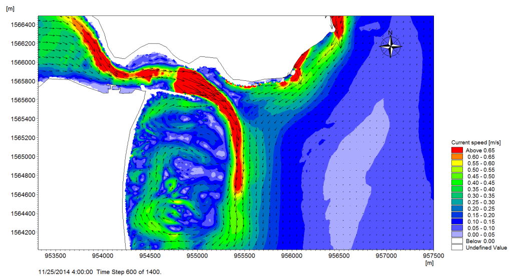
(a) High tide, low velocities



(b) Low tide, low velocities



(c) High tide, high velocities



(d) Low tide, high velocities

Figure 28: Current flow during dominant NE monsoon conditions for high and low tide (MIKE21 models Thủy Lợi University)

These flow circulations are conceptualized by schematic figure 29. The figure shows the formation of eddies due to a sudden asymmetrical widening of the coastline. Behind the headland flow rates of the streamlines decrease and create turbulence in the lee zone. Small eddies occur along the shore, created by friction of the coastline. Figure 29b shows a fully developed situation, however, such conditions are less likely to appear due to changing conditions of the tide and hydrodynamics. During field observations, arc-shaped formations were observed which could indicate the small eddy-friction processes, see figure 51 in appendix D. No such beach shapes were observed north of the headland, see figure 50.

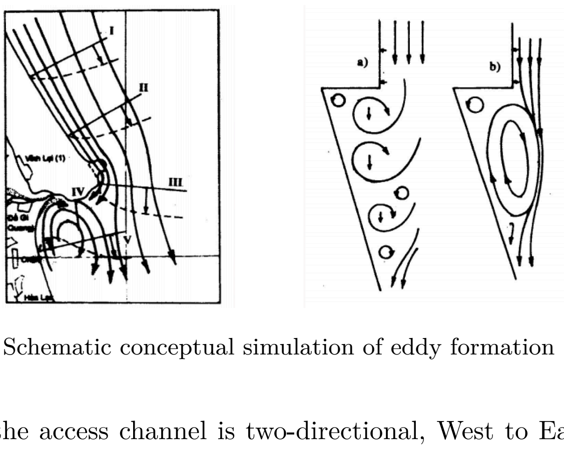


Figure 29: Schematic conceptual simulation of eddy formation (Bieu 2008)

The current flow inside the access channel is two-directional, West to East during high tide and East to West during low tide. Flow velocities however differ along the tidal cycle continuation and differ location-wise inside the channel. Based on flow simulation with MIKE21, the highest flow velocities were calculated at the inlet of the channel, being: Vmax rising tide is 0.46 m/s and Vmax falling tide is 0.62 m/s (Duc, Anh, et al. n.d.). This shows that falling conditions have a higher flow velocity. The difference can be explained by the fact that the rising tide has a longer duration than the falling tide, see figure 25.

6.2.3 Morphodynamics

The morphodynamics of an area is the process by which morphology affects the hydrodynamic processes in such a way that it influences the further evolution of the morphology itself. The area is a constantly changing environment in time, from landscapes to bathymetry. The majority of coastal morphodynamics is caused by sediment transport.

Geography
The local coastal system is located in the Province of Bình Định. The Province has a coastline that stretches 134 kilometres (north-south), which is quite a significant landscape given the Province's latitude covers 'only' 55 kilometres and the land-covered area is about 6025km^2. However, 70% of the province's area has an average altitude of 500 to 1000 metres the highest point being about 2100 metres. The lower areas are found in the centre of the province, a little north of the province's capital Quy Nhơn and the coastal areas. As in the rest of Vietnam lagoons, bays or estuaries are quite common along the coast. Often, these coastal inlets function as locations for (fishery) ports, due to its naturally formed shelter advantage. Besides the inlet systems, the province also has four main rivers of which the Côn River is the biggest and can be used for an inland shipping waterway. This summation already indicates the geological complex region that Bình Định is in, see figure 30.

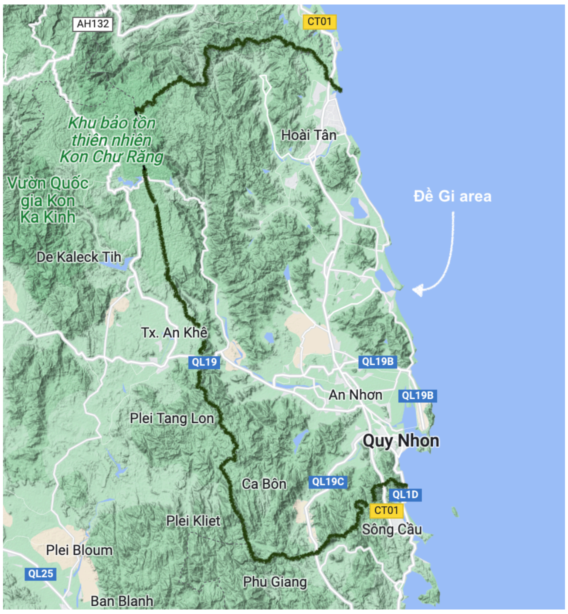


Figure 30: Geography of Bình Định Province (Google Maps, terrain)

The coastal inlets as found along the coast in Bình Định can be categorised as tidal inlets or estuary entrances. Also, the term lagoon is often used, as before in this report. Generally, besides the freshwater runoff of a river, estuaries are typically tide-dominated. Meaning that the water motion in estuaries is controlled more by the tide than by the river discharge. Furthermore, the sediments are mainly imports originating from the coastal system (Bosboom and Stive 2023).

However, lagoons tend to have no or little river flow discharge. Additionally, the dynamic flow of water is often sluggish and slow, where estuaries usually have higher flow velocities (Miththapala 2021). In Bình Định, the La Tinh River has a minimal discharge in the inlet and is negligible (Đỗ 2017). Often lagoons and estuaries are difficult to distinguish since their characteristics have similarities and so it seems to be in this case. It turns out that available literature also uses inconsistent terminology. For this project, the following choice of words seemed most reasonable:

> "*Geologically, a lagoon is an evolving coastal landform that goes from a shallow open embayment or* ***estuary valley*** *to a partially enclosed* ***back-barrier lagoon****, and then, with progressive infilling, to a marsh or* ***deltaic-filled lagoon***" (Nichols 1989)

For that, this report uses the Đề Gi estuary (valley) which functions as a gorge to the Nuoc Ngot lagoon.

The area of the lagoon is 1390 hectares and only a small part of the lagoon is used as a port. The port is mainly located on the south and east sides of the Nước Ngọt lagoon. Where the villages Vĩnh Lợi and An Quang are located on both sides of the Đề Gi estuary in different districts, see subsection 5.1.1. The fishing industry in Đề Gi has developed on its own over the years due to its ideal geography and local entrepreneurship.

As can be seen in figure 22, the lagoon is sheltered by a peninsula. The characteristics of the headland type of terrain near the access channel are low-crested granite magma formations, strongly eroded and smoothened by a history of denudation processes in weathering and tidal impact. The surrounding area of Đề Gi consists of a wide variety of sand grain sizes. This is due to the influence of many factors, like ocean waves, the discharge of the La Tinh and Sông Lại Giang rivers (near Tam Quan), a history of flooding and strong windy conditions. Based on these driving mechanisms the most eye-catching example of terrain agglomeration is the becoming of sand dunes and dikes. The main driver is the seawind (aeolian transport) due to which many of these formations are found along the Bình Định coastline, and so an accumulation sand dune is formed against the headland, see figure 31. More south of the lagoon and near the La Tinh River mouth more muddy soil is found. Even small amounts of mangrove species grow, maintained by a small-scale nature reserve project.

(a) Sand dune at headland (Duc, Anh, et al. n.d.)

(b) Dune landscape north of headland (Google Maps, May 2023)

Figure 31: Sand dune and landscape at northern beach of Vĩnh Lợi Cape

Bathymetry

As described in section 6.1, the continental shelf of Central Vietnam is rather small. In general, shelves break at a constant depth of 100 to 200 metres. This implies that narrow shelves have rather steep slopes (Bosboom and Stive 2023).

Figure 32, confirms this implication. The bathymetry contours steepens rapidly along the coastline. Generally, it can be obtained that within 2 kilometres distance from the shore, the water depth has reached beyond 30 metres, resulting in a slope of about 1:65. For the beach slope, field observations (appendix D) at different locations, north and south of the headland, showed an average beach slope of 1:22 (12.5 degrees). This is rather steep, especially because it is not a seasonally shaped winter beach since the summer monsoon season is ending near.

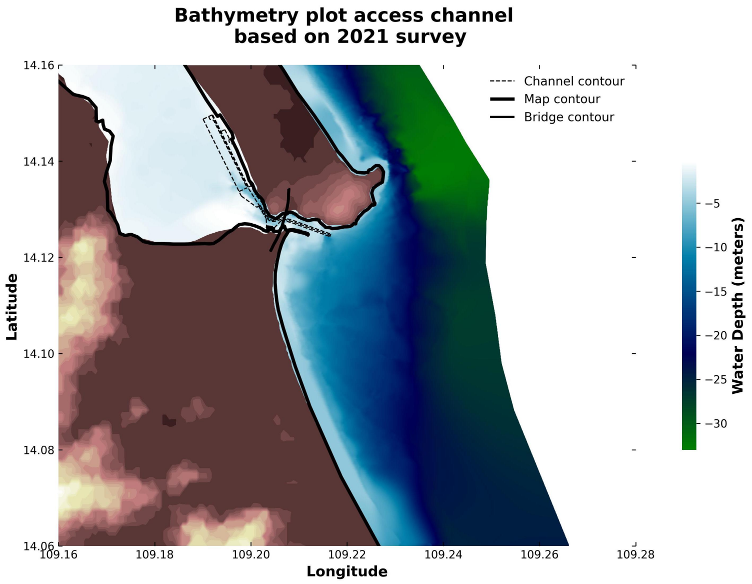


Figure 32: Bathymetry situation Đề Gi Area by survey 2021

Aside from cross-shore bathymetry, the alongshore shape of the coast shows the clear interruption by the granite headland mountain. Directly south of this headland, the seabed slope is significantly milder than further south and north. This might be due to several hydraulic phenomena that appear in the coastal system, varying per season.

When examining the bathymetry of the Đề Gi estuary from an aerial perspective, various features become apparent. These aerial images were acquired from Google Earth spanning the years 2010 to 2022. As depicted in the images in figure 33, the presence of shoals is noticeable. It appears that these shoals have been gradually moving towards the lagoon over the years. However, around 2015, the shoals disappeared. Furthermore, there is a stable sand bump at the landward side of the breakwater, which has remained relatively consistent over the years. In the bottom last image of figure 33, it is apparent that a bridge is planned to be constructed at this sand bump.

When analyzing the coastline, a noticeable retreat is observed. The coastline appears narrower in the bottom last image compared to the images above it. Around 2020, aquaculture farms were situated in areas previously occupied by plants or trees. Moreover, over the years, the landward side of the breakwater has become more exposed to the sea or other environmental conditions. Looking more at what's happening in the channel, it can be observed that, around the time of the bridge's construction, more aquaculture farms were located within the channel.

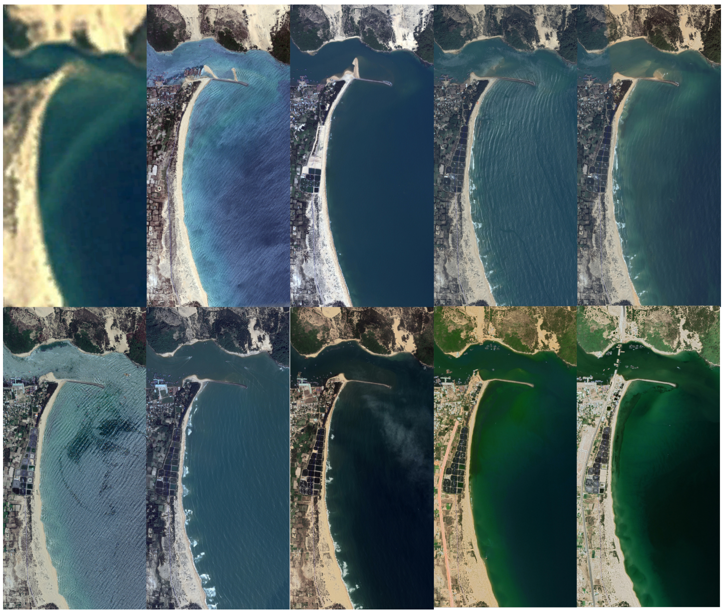


Figure 33: Satellite images of the Đề Gi estuary, 2010-2022 (Google Earth)

Sediment transport

The sedimentation processes around the Đề Gi estuary are very complex because there are multiple drivers that contribute to various sedimentation transports. The primary factors that result in the transportation are due to:

- The NE monsoon
- The SW monsoon
- The asymmetrical shape of the Đề Gi estuary topography
- The net accretion processes inside the lagoon

As mentioned in section 6.1 and paragraph Wave conditions, the highest wave heights occur during the NE monsoon. Waves are stirring up the sediment and the alongshore current is responsible for the sediment movement. Higher wave heights enhance the stirring of sediment. Due to this occurrence, the NE monsoon is the primary force behind the movement of sediment. The dominant wave direction in this period is 61.7° (see table 10). As a result of the waves approaching the coastline at an angle, see figure 24, an alongshore current can develop flowing southwards creating a sediment transport also towards the south. As explained in paragraph Current, the flow of the current around the headland meets the outflow (during low tide) at the Đề Gi estuary near the inlet of the access channel which causes a part of the sediment that travels with the alongshore current to be deposited in this region and the other part of the sediment will be transported further southwards, contributing to the dynamic sediment transport balance, figure 34 (Duc, Tung, et al. 2019). The deposited sediment will contribute to the growth of an ebb tidal delta. The flood (inside the lagoon) and ebb tidal deltas play an important role in the sedimentation transports in estuaries. When the ebb tidal delta receives more sediment of external factors, like the deposition of sediment explained above, the sediment demand, supplied from the lagoon, will reduce, leading to accretion of the access channel (Bosboom and Stive 2023). Besides the southward flowing alongshore current in the NE monsoon, the high wave energy (especially during extreme events) also has an effect on

the sediment movement. Waves with increased wave energy go farther down the access channel, creating accretion in this region (Duc, Anh, et al. n.d.).
Several studies investigated the influence of the tide during NE monsoon, as described in paragraph Current. During low tide, the current flows out the channel meeting the alongshore current as described above. During high tide, the current will flow through the channel towards the lagoon and because the velocities during flood are not that high, sediment can settle more easily in the access channel. Furthermore, during high tide, there is a current that circles around the breakwater allowing sediment to transport likewise in this direction (Duc, Anh, et al. n.d.).

Another driver that contributes to the sediment transport of the Đề Gi area, is the SW monsoon, figure 34. In this monsoon, waves approach the Đề Gi coastline with an angle creating an alongshore current and sedimentation transport towards the north. A part of this sedimentation transport is in dynamic balance with the southward sedimentation transport whereby the sediment movement during the NE monsoon is dominant. Another part of the northward sedimentation transport is blocked because of the breakwater causing accretion directly south of the construction. Additionally, due to the fact that the breakwater is permeable, sediment can pass through creating accretion in the access channel directly next to the breakwater (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).
During extreme events, high wave heights in storms coincident with high tide (can be in both monsoons), can lead to overtopping at the breakwater. Overtopping can induce sediment deposits at the breakwater crest or in the access channel (Duc, Tung, et al. 2019).

In a study that deals with the sedimentation trends at the Đề Gi area, it is stated that the headland north of the Đề Gi inlet will block the sedimentation transport going southward during the NE monsoon (Duc, Tung, et al. 2019). When comparing the situation with the same wave heights, the sedimentation transport during the SW monsoon should be more dominant (Duc, Tung, et al. 2019). However, in real life the average wave height is significantly larger in NE monsoon, see table 10. Waves will break more offshore due to its high wave height resulting in the surfzone being more seaward. The alongshore current will develop more offshore and the question is how much influence the headland will have on this current flowing southward.

The third driver is the asymmetrical shape of the Đề Gi estuary topography, figure 34. During the NE monsoon a large eddy circulation develops which generally flows northwards along the southern coast of the Đề Gi area, see figure 29. This flow creates strong accretion processes on both sides of the permeable breakwater.

The last main driver for the sediment processes developing in the Đề Gi estuary occurs inside the lagoon, figure 34. Parts inside the lagoon erode which causes a net accretion inside the lagoon that is transported towards the access channel. Some of this sedimentation is deposited in front of the channel (flood tidal delta) while the other portion is transported through the channel due to flow occurring during low tide.

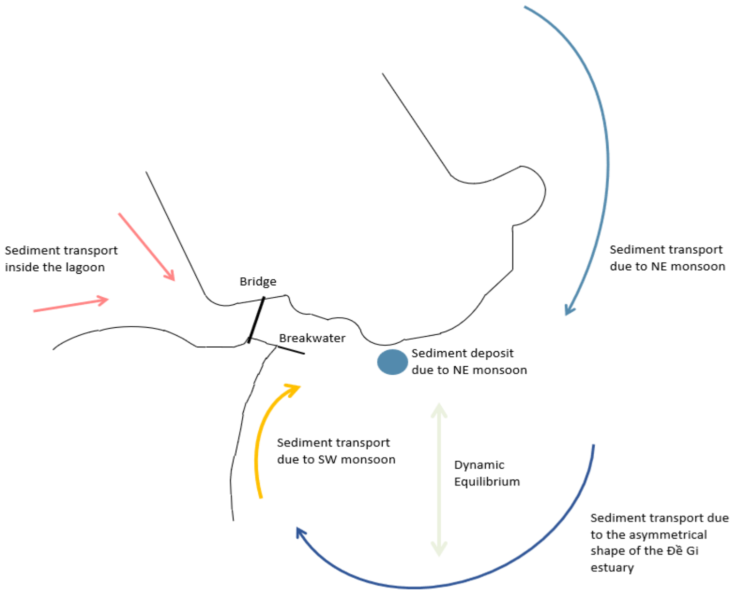


Figure 34: Scheme of the four main sediment transport drivers around the Đề Gi estuary area

In subsection 6.2.3, a sand dune at the headland is mentioned. According to Duc et al., during the NE monsoon, amongst heavy rainfall, sand slides off the sand dune and is subsequently deposited in the access channel. Nevertheless, the precise volume of sand being eroded from the dune has not been thoroughly examined. Duc et al. analyzed this type of sediment transport within the access channel and found that this sediment has the potential to cause blockage in the channel (Duc, Anh, et al. n.d.).

6.3 Access channel

The nautical access channel or Đề Gi estuary is an important gateway for the fishery fleet, it is a threshold for the port to be functioning. This section examines the current state of the channel exploring various topics, including its functionality, and interventions such as the newly built bridge, the existing breakwater and dredging activities. Furthermore, it analyzes the future perspective for the channel.

6.3.1 Functionality

The access channel connecting the lagoon to the East Sea is used for navigation by fishing vessels entering and exiting the lagoon, which hosts the storm shelter and port. The access channel has a width of 280 metres and a length of roughly 1.2 kilometres. The navigable part of the channel has a varying width of 55-200 metres, where the channel narrows when entering and expands at the Đề Gi fishing port. Signalling marks the position of the navigation channel in the form of red and green buoys, which the vessels have to pass within a 5-50 metre distance according to the inland waterway signalling rules.

Meanwhile, the access channel also hosts aquaculture farms along the side, outside of the marked navigation channel. The aquaculture farms are floating structures which are either used for growing pelagic fish in nets or shellfish on lines. The aquaculture farms are reached by small boats from the adjacent land. Furthermore, small fishing vessels use the access channel as a fishing ground (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022).

Fleet
The vessels using the access channel are mainly fishing vessels of various sizes and fishing-related vessels, like small transport boats and supply vessels. The current fleet of the Đề Gi anchorage area is summarized as:

	Number of vessels
Total	3.144
<50 CV	1.258
50-90 CV	216
90-150 CV	91
150-400 CV	784
>400 CV	795

Table 14: Current fleet of the Đề Gi anchorage area (Binh Dinh department of Agriculture and Rural development 2020)

The largest share is small vessels with a CV below 50. These boats are constructed out of fibreglass and it's very common that they are full round with a simple rudder and relatively large engine. These small vessels don't per definition follow the marked navigation channel, which was observed during a field trip. The medium to large size vessels are mainly constructed out of wood with roughly 5 separate hulls where caught fish is stored and cooled by crushed ice. In the largest vessel class, there are 30 steel-hulled fishing vessels at the moment. These vessels are of higher quality than wooden vessels and stay at sea for a longer period (see figure 35). On a regular basis, 700 vessels enter and exit the port.

(a) Small round vessel

(b) Medium-large vessel

(c) Large steel-hulled vessel

Figure 35: Vessels observed in Đề Gi port (private images)

The fleet is classified by engine size. Up to 600 CV 10 classes are specified. The table below gives an overview of the vessel specifications:

Type	Length (m)	Width (m)	Draught (m)	Height (m)	Displacement (t)
20CV	11.0	2.8	1.0	-	12
33CV	15.3	3.8	1.1	1.4	25
45CV	16.7	4.0	1.1	1.4	30
60CV	18.0	4.6	1.2	1.5	47
90CV	23.0	4.8	1.4	1.9	55
135CV	23.0	4.8	1.5	2.2	67
200CV	24.0	5.6	1.7	2.8	110
300CV	25.0	6.0	1.9	2.8	135
400CV	28.0	7.0	2.4	3.7	290
600CV	32.0	8.0	3.0	3.8	350

Table 15: Technical specifications of traditional fishing fleet

6.3.2 Interventions

In the access channel, several interventions have been implemented, including the construction of a bridge, a breakwater and dredging activities. Further details and explanations of these interventions are provided in the following sections.

Bridge
In 2022 a bridge over the Đề Gi estuary was completed connecting the northern Phù Mỹ district with the southern Phù Cát district as part of the DT 639 coastal road project (see chapter 5). The bridge spans 320 metres and is supported by 8 pillars, creating 7 smaller spans. The spans near the waterfront are 40 metres wide. The main access channel span is 90 metres wide, which is sufficiently wide to host the 36-metre-wide access channel intended for larger vessels. Adjacent to the main span there are two 55 metre spans which can be used by smaller vessels. Field observations however showed that the northern 55-metre span is used for aquaculture leaving only one navigable 55-metre span. The clearance height of the main span is 9.5 metres. The figure below gives an overview of the bridge at the main span. Further imagery can be found in appendix F.

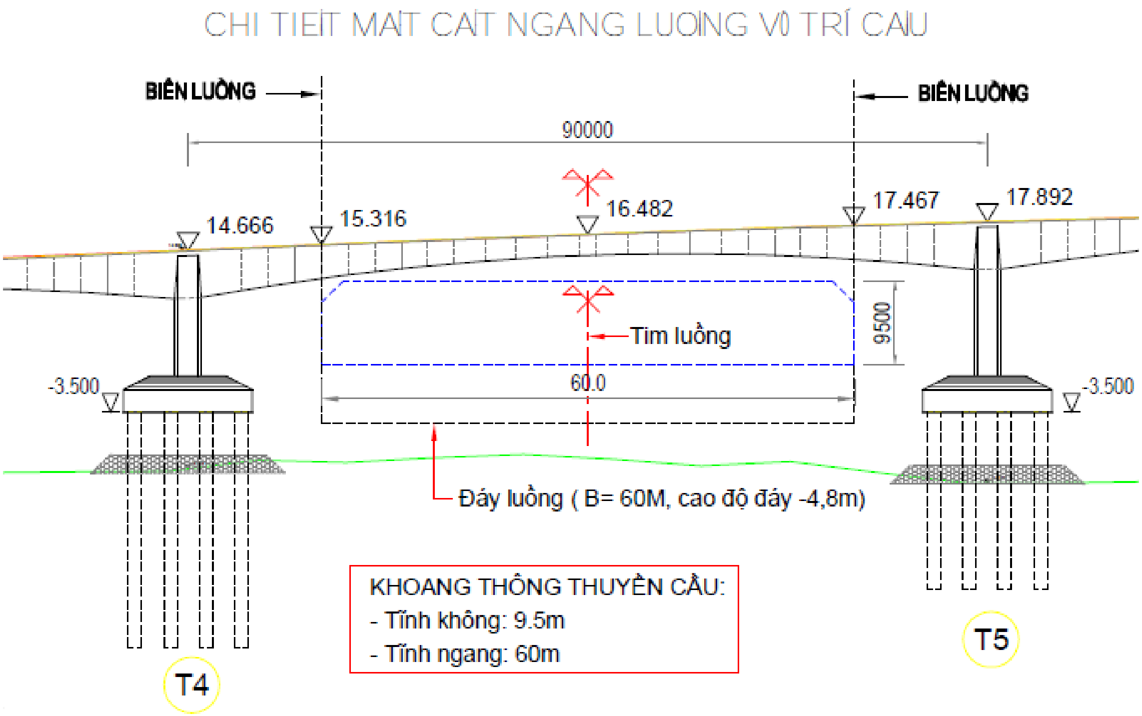


Figure 36: Technical drawing cross section main span Đề Gi bridge (the initial 60 m wide access channel is replaced by a 36 m access channel)

Breakwater

A 550-metre-long and approximately 25-metre-wide breakwater made of concrete tetrapods is situated to the south of the Đề Gi estuary's inlet, see figure 37 (additional figures of the breakwater can be found in appendix D). The breakwater was constructed to prevent accretion processes at the entrance of the access channel, allowing ships to enter the Đề Gi port with ease. Additionally, the breakwater must hinder coastal erosion on the southern side of the Đề Gi estuary's inlet (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022). The construction of the breakwater was completed in 2003 (Duc, Tung, et al. 2019).

(a) Northward side **(b)** Top

Figure 37: Breakwater

Several studies investigated the coastline change rate in the Đề Gi area and what influence of the breakwater on the coastline. These researches are based on GIS (Geographic Information System) and remote sensing methods over three different periods: period 1965-2003, period 2003-2012 and period 2012-2014 (Duc, Anh, et al. n.d.). In figure 38, the three periods of the coastal evolution rates can be observed. The inlet of the Đề Gi estuary is represented by distance 0 on the x-axis. The distance from the inlet is shown by the negative values at the x-axis for the northward direction and the positive values for the southward direction. Do Minh Duc et al. examined the coastline changes by using a parity function analysis for each period. This method's strength lies in its capacity to quantify the relationship between coastline changes and the amount of displaced sediment (erosion or accretion). Per period, the sediment volume that is deposited or eroded in the inlet of the Đề Gi estuary can therefore be estimated (Duc, Anh, et al. n.d.).

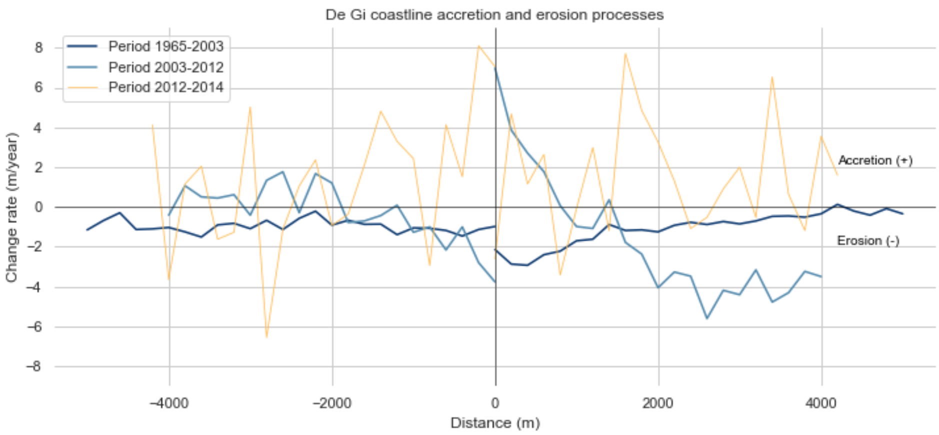


Figure 38: The erosion and accretion rates of the north and south side of the Đề Gi breakwater (Duc, Anh, et al. n.d.)

Before the breakwater, period 1965-2003, the annual volume of sediment deposited at the inlet was about 2760 m^3/year. The change rate in figure 38 shows only erosion processes along the coastline.

The coastline (north and south of the breakwater) in this period, eroded with an average rate of 1.2 m/year (Duc, Anh, et al. n.d.).

In the period of 2003-2012, the building and operation stage of the breakwater was started and finished. The influence of the erosion processes of the inlet at the north side is limited to a distance of about 1700 m (see figure 38). At the southern part of the breakwater, sedimentation processes occur up to approximately 900 m of the breakwater. The accretion rate is varying from 0.4-6.7 m/year. This makes sense because the breakwater blocks the sediment transport resulting in more depositing of the sediment south of the breakwater. The volume of sediment deposited at the Đề Gi inlet will be higher, namely 24840 m^3/year. At a distance of 1450 metres from the inlet, the coastline tends to erode similar to the long-term developments with an average erosion rate of 1.0 m/year (Duc, Anh, et al. n.d.).

Period 2012-2014 shows that the northern shoreline is mainly accreting until a distance of 2650 metres from the breakwater. The south side up to 350 metres of the breakwater is accrued at a rate of about 9.6 m/year. The overall shoreline is mainly accruing. The volume of sediment deposited at the Đề Gi inlet is 2390 m^3/year (Duc, Anh, et al. n.d.).

The breakwater contributes to a decrease in erosion processes on the south side of the inlet of the Đề Gi estuary. However, several studies demonstrate that the breakwater is not sufficient enough to prevent the accretion processes in the access channel due to the fact that the length of the breakwater is too short, too permeable and the elevation height too low (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022). The motivation for the sedimentation processes can be read in subsection 6.2.3 paragraph Sediment transport. The volume of sediment deposited at the Đề Gi inlet before the breakwater (period of 1965-2003) and a long time after the construction of the breakwater (period of 2012-2014) is not very different (Duc, Anh, et al. n.d.). As stated in the research of Duc et al., 'the problem of channel filling has existed before, improved since the southern breakwater was installed, but got worse in later years' (Duc, Anh, et al. n.d.).

Dredging activities
According to Thuy Loi University professors, dredging activities are conducted in the Đề Gi estuary following the Northeast monsoon to prevent the shallowing of the access channel. However, there is currently no available data regarding this maintenance. In subsection 6.2.3, within the paragraph Bathymetry, satellite images reveal the presence of shoals in the access channel. It is likely that these shoals have gradually disappeared in subsequent years, possibly as a result of the dredging activities.

6.3.3 Future

The KND project foresees future growth for the port and storm shelter due to economic development and policy changes regarding fishing hubs in the Bình Định region. Regarding the access channel, the following changes are to be expected:

- Regular visit of 700 vessels
- Storm shelter capacity of 2000 vessels of which 1000 are relocated from Quy Nhơn
- Largest vessel capacity 300 CV, however, advised designing for vessels >400 CV, since there are already 671 vessels having this amount of power
- 900 vessels <15 metre
- 900 vessels 15-24 metre
- 200 vessels >24 metre

- Construct a navigation channel with 36-metre width, a length of 2250 metres and a bottom level of -4.8 metres relative to Hon Dau elevation.
- Design for 20-year lifetime
- Repair/improve breakwater at the south side of the access channel to prevent sedimentation in the channel
- Create an embankment at the foot of the Hòn Heo mountain and dune to prevent sedimentation

Dimensions of the channel are based on TCVN 11153:2016 [Storm shelter anchorage area for fishing vessels, General requirements]:

- The channel must be wide enough for medium-sized fishing vessels to enter and exit simultaneously (2-way) channel. The largest fishing vessel type can enter and exit according to 1-way channel standards.
- The minimum width of the channel is 8 times the width of a medium-sized fishing vessel or 4-5 widths of the largest vessel entering or leaving the mooring area.
- The minimum channel depth must equal 1.1 - 1.5 the draught of the largest fishing vessel leaving the anchorage area at the lowest water level.
- The minimum curvature radius of the navigation channel is 4 times the maximum length of the ship.

6.4 Accessibility

According to the Cambridge Dictionary, accessibility means *"the quality of being able to be entered"* (*Cambridge Dictionary* n.d.(a)). In this research, the quality of accessibility of the Đề Gi estuary will be evaluated based on four different aspects: (1) safety, (2) robustness, (3) durability, and (4) effectiveness.

- Safety: a place where individuals are secure and not in danger or at risk (*Cambridge Dictionary* n.d.(b)).
- Robustness: refers to a situation in which the system is strong and unlikely to fail (*Cambridge Dictionary* n.d.(c)).
- Durability: refers to being able to last a long time without becoming damaged (*Cambridge Dictionary* n.d.(d)).
- Effectiveness: refers to the ability to be successful and produce the intended results (*Cambridge Dictionary* n.d.(e)).

The risks that may arise when the channel is not accessible concerning safety, robustness, durability and effectiveness are as follows:

- Safety: inaccessibility can lead to navigation threats where vessels can not navigate securely through the channel. The risk of grounding incidents and collisions increases, resulting in concerns for the safety of individuals, vessels and environment surroundings. Difficulties in navigation necessitate slower vessel speeds and more alertness. The size and type of vessels that can successfully use the channel may be constrained. Furthermore, grounding incidents and collisions can result in delays and operating downtime. Navigation threats can also impact Đề Gi's reputation, potentially discouraging vessels from seeking haven in its storm shelter and port. The risk lies in the potential decline in appeal for these maritime facilities due to navigational challenges.

- Robustness: the channel must always be functioning meaning vessels can always navigate through the access channel without being constrained. The risks that may occur are the dependency of maintenance, the vulnerability of the system after extreme weather conditions, or daily natural processes.
- Durability: the access channel must be able to last a long time. The Đề Gi estuary is an important gateway for the fishery fleet and is a threshold for the port to be functioning. The KND project foresees future growth for the port and storm shelter whereby the vessel fleet will change. Bigger vessels will navigate through and must not be restricted due to a limit on draught. Also, the access channel must be able to last while the climate is changing.
- Effectiveness: the ability to be successful and produce the intended results must not decrease. For example, the efficiency of maritime operations, especially in busy waterways will reduce when the waiting time is higher or when the vessel speed inside the channel is lower. Furthermore, when a part of the fleet can not enter the channel, it may result in economic losses for the local community or potential failure to achieve the vision of Bình Định.

Previous sections have explored various facets of the coastal system within the Đề Gi area. These components may have implications for the accessibility of the port and storm shelter in the KND project. Importantly, these factors should not compromise the safety, robustness, durability, and effectiveness of the access channel, as such compromises pose serious threats. Therefore, this chapter will explain how hydraulic elements influence accessibility, leading to a variety of potential challenges. The aim is to get a qualitative opinion on the navigability of the channel and where possible add a quantitative argumentation. Finally, the accessibility is examined on the four factors previously mentioned.

6.4.1 Influences of the hydraulic facets

To identify bottlenecks hindering the accessibility of the access channel, an analysis will be conducted to examine the influences of hydraulic facets on the coastal system of Đề Gi. The analysis will be focused on the three hydraulic facets of the Đề Gi coastal system: (1) climate, (2) hydrodynamics and (3) morphodynamics. These facets have been explained in earlier sections.

Climate influences the accessibility of the access channel in different meteorological ways. Precipitation is one of the important meteorological aspects in the Đề Gi area. Heavy rainfall can lead to an accelerated runoff from land-moving sediment in the access channel. The sediment can accrete in the access channel reducing the depth. Shallowing of the channel makes navigation more difficult which increases the possibility of ships becoming stranded. However, rainfall contributes also to an increase in water level which can be beneficial for navigation and provides extra depth for vessels to manoeuvre to the access channel. Besides the precipitation, storms and wind are other meteorological aspects that contribute to the influence of the accessibility of the access channel. Storms are frequently accompanied by severe winds that produce high waves. Navigation via the access channel is more challenging when the waves are high because wave action can have an impact on the stability and safety of the vessels. Strong winds can also lead to storm surges. Storm surges will cause fluctuations in water levels which makes navigation through the access channel challenging, especially when the fluctuations are sudden. Vessels prone to fluctuations in water depth, particularly those with deeper draughts, are at risk of aground. Furthermore, the coastline of Đề Gi can erode under prolonged wind exposure, particularly after a storm, leading to a retreat of the shoreline and more suspended sediment. This suspension has the potential to flow into the access channel, deposit there, and then build up there. The final meteorological aspect that will be discussed is climate change. As mentioned in subsection 6.2.1, the risk of flooding increases due to climate change. Additionally, the intensity and impact of cyclones are expected to change. In brief, if extreme events become more frequent and more intense, the effects of meteorological aspects (precipitation, storm and wind) and the associated risks described above will also become more pronounced.

Climate-related factors result in hydrodynamics. In subsection 6.2.2, the associated hydrodynamics (wave conditions, tidal conditions and flow current) that occur at the Đề Gi estuary are discussed. The highest wave heights occur during the NE monsoon because the waves can develop over a large distance. As previously stated, high wave action can have a negative impact on the stability and safety of the vessels, especially on small vessels. During the SW monsoon, the average wave heights are smaller. However, the wind direction is not favourable for vessels to manoeuvre to the access channel. Besides the breakwater, there is no blockade that creates shelter against the southwestern wind, like the headland creating shelter against the northeastern wind. Another hydrodynamic factor that can affect the accessibility of the channel is the tide. The Đề Gi estuary's water level can change depending on the tides' amplitude. During low tide, the water level of the access channel decreases, potentially limiting the draught of vessels that can safely navigate. Additionally, tidal currents (in- and outflow of the lagoon) can make it difficult for vessels to navigate against the current. Vessels may need to exert more force and power to move against the current if it creates resistance.

The majority of coastal morphodynamics is caused by sediment transport and this transport also has a major influence on the accessibility of the access channel. There are multiple drivers for sediment transport that result in accretion processes in the channel. During the NE monsoon, the accretion processes are due to the growth of the ebb tidal delta, the high wave energy, the slow velocities during flood periods and the large eddy flow. During the SW monsoon, accretion processes happen near the breakwater due to the northward movement of the sediment and the permeability of the breakwater. Sediment that is transported inside the lagoon towards the access channel settles at the flood delta or in the channel itself. Furthermore, sediment transport during extreme events and sliding off the sand dune will also result in accretion in the access channel. All these drivers for accretion processes in the access channel lead to the reduction in water depth and narrowing of the channel. This creates risks for vessels, like running aground or facing navigation difficulties.

6.4.2 Bottlenecks

Through an analysis of how the coastal system affects the access channel and the associated risks it introduces, bottlenecks become evident. The two main bottlenecks that reoccur in the previous subsection are the draught and the width of the channel. These bottlenecks can hinder the accessibility of the channel, raising concerns about its safety, robustness, durability and effectiveness. Identifying the bottlenecks helps where to improve the accessibility of the channel. However, the width of the access channel will not be taken into account, because the channel width in the KND project assumend to be sufficient.

Furthermore, climate change is a potential bottleneck. As described in subsection 6.2.1 paragraph Climate change, a report of the IPCC on climate change stated, that Vietnam is in the group of "Most Vulnerable Countries" to climate change (Trung 2023). Furthermore, the UN Development Programme Vietnam has identified climate change as "the most pressing threat facing Vietnam over the next couple of decades" (UNDP 2018). The intensity of extreme conditions will increase, which will affect the safety, robustness, durability and effectiveness of the access channel. To enhance the accessibility of the access channel, further investigation will be done on the two bottlenecks: the draught of the channel and the impact of climate change.

6.4.3 Results

As the previous subsection describes, there are two main bottlenecks that affect the accessibility of the channel: the channel's draught and the impact of climate change. To determine the influence of these challenges, a more thorough examination of the channel's bathymetry is provided. Figure 39 is a zoomed in version of figure 32 where the Đề Gi estuary is clearly visible. The water depth (in metres) along the latitude and longitude of the estuary can be observed. Additionally, the location of the planned navigation channel, the bridge, the breakwater and the jetty (on the west side of the bridge) are situated in figure 39.

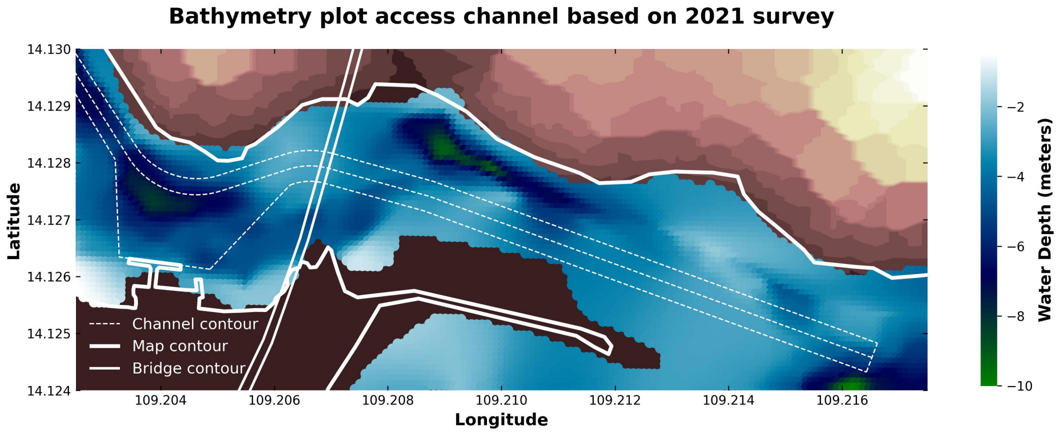


Figure 39: Bathymetry situation access channel by survey 2021

As mentioned in subsection 6.3.3, the KND project foresees future growth for the port and storm shelter. There are changes to be expected such as the capacity and size of vessel types. In section 6.3 several characteristics of the vessel fleet are described: type of vessel, amount of number of vessels in 2020, the technical specifications of the vessel fleet in 2020 and the future changes of the vessel fleet. A depth assessment is conducted based on different types of vessels to determine where and how significant the bottlenecks are that affect the accessibility. The assessment classifies the different types of vessels into five categories: (1) Type I, (2) Type II, (3) Type III, (4) Type IV and (5) Type V (see table 16). These categories are based on the engine power. For example, Type I has an engine power of 50 chevaux-vapeur (CV) or less. Each vessel category has a maximum draught, see third column of table 16. The maximum draught serves as a baseline when assessing the water depth. However, as described in subsection 6.3.3, the minimum channel depth must equal 1.1-1.5 times the draught of the largest fishing vessel, the design draught (see table 16). A safety factor of 1.5 was chosen in this assessment because it provides the safest conditions (one of the qualities where the accessibility of the Đề Gi estuary will be evaluated). Columns five, seven and nine of table 16 represent the number of vessels in three different classifications: those that are currently registered in 2020, daily vessels in the future and the future number of vessels that will use the storm shelter (for example under extreme conditions). The three adjacent columns provide the number of vessels in percentages. The number of vessels is based on previously provided data and very rough estimates (see tables 14, 15 and future changes described in subsection 6.3.3). For a better visualization of table 16, see appendix G.

Type	Engine power (CV)	Max. draught (m)	Design draught (m)	Current registered number of vessels	%	Future number of vessels daily	%	Future number of vessels in storm shelter	%
I	≤ 50	1.1	1.65	1300	40	600	85	900	45
II	≤ 100	1.4	2.1	200	7	70	10	450	22
III	≤ 200	1.7	2.55	100	3	15	2	450	22
IV	≤ 400	2.4	3.6	800	25	10	1	100	5
V	≥ 600	3	4.5	800	25	5	1	100	5
			Total amount of vessels:	3200	100	700	100	2000	100

Table 16: Vessel categorization

Figure 40 and figure 41 display the outcomes of plotting the under keel clearance (UKC) for various vessels types from table 16 against different water levels: MHW, MSL and MLW. UKC is the vertical distance between the lowest point of a floating vessel and the fixed bottom (bathymetry). The UKC depends on the bottom level, the water level (MHW, MSL and MLW) and the vessel draught. In figure 40 and figure 41 the bathymetry is taken as the basis to which the water levels are added. From this, the vessel design draught is subtracted. A negative outcome (red) means no sufficient water depth and a positive outcome (green) means sufficient water depth. It is important to keep in mind that MSL is more prevalent than MHW and MLW (see figure 26). Figure 40 are computed spatially, which gives an indication of which parts of the channel are navigable to determine. Figure 41 are computations along the planned navigational channel axis which indicates the margins of navigability on that location. The channel axis displayed in this figure is at the middle of the access channel.

The computations are based on several assumptions:

- The channel location is the original proposed location taken from the design drawings of the KND project.
- The minimum channel depth is 1.5 (safety factor) times the draught of a vessel (design draught).
- Bathymetry survey data from 2021, assuming normalised water levels with respect to CD (Hon Dau).
- Water levels based on converted statistical data from Quy Nhơn (see subsection 6.2.2).
- Current registered fleet is based on statistical data from 2020 (see section 6.3).
- Proposed future for fleet, daily visits and storm shelter are as described in the KND project.

A short explanation of the main characteristics of figure 40:

- 5 vessel types are considered.
- 3 water levels are considered: MHW, MLW and MSL.
- Green indicates sufficient depth according to design standards.
- Green-red indicates sufficient depth for vessel draught, but not sufficient to meet design standards.

- Red indicates insufficient depth for vessel draught.
- 5x3 matrix with increasing ship size and decreasing water level.

A short explanation of the main characteristics of figure 41:

- 5 vessel types are considered.
- 3 water levels are considered: HW, LW and MW. Including a 99% confidence interval of the water level as demonstrated in figure 26.
- Green indicates sufficient water depth according to design standards.
- Red indicates insufficient depth according to design standards.
- The graph indicates the deviation from the design depth, with the 0-line being the perfect fitting depth.

The full Python computation can be found in appendix H and I.

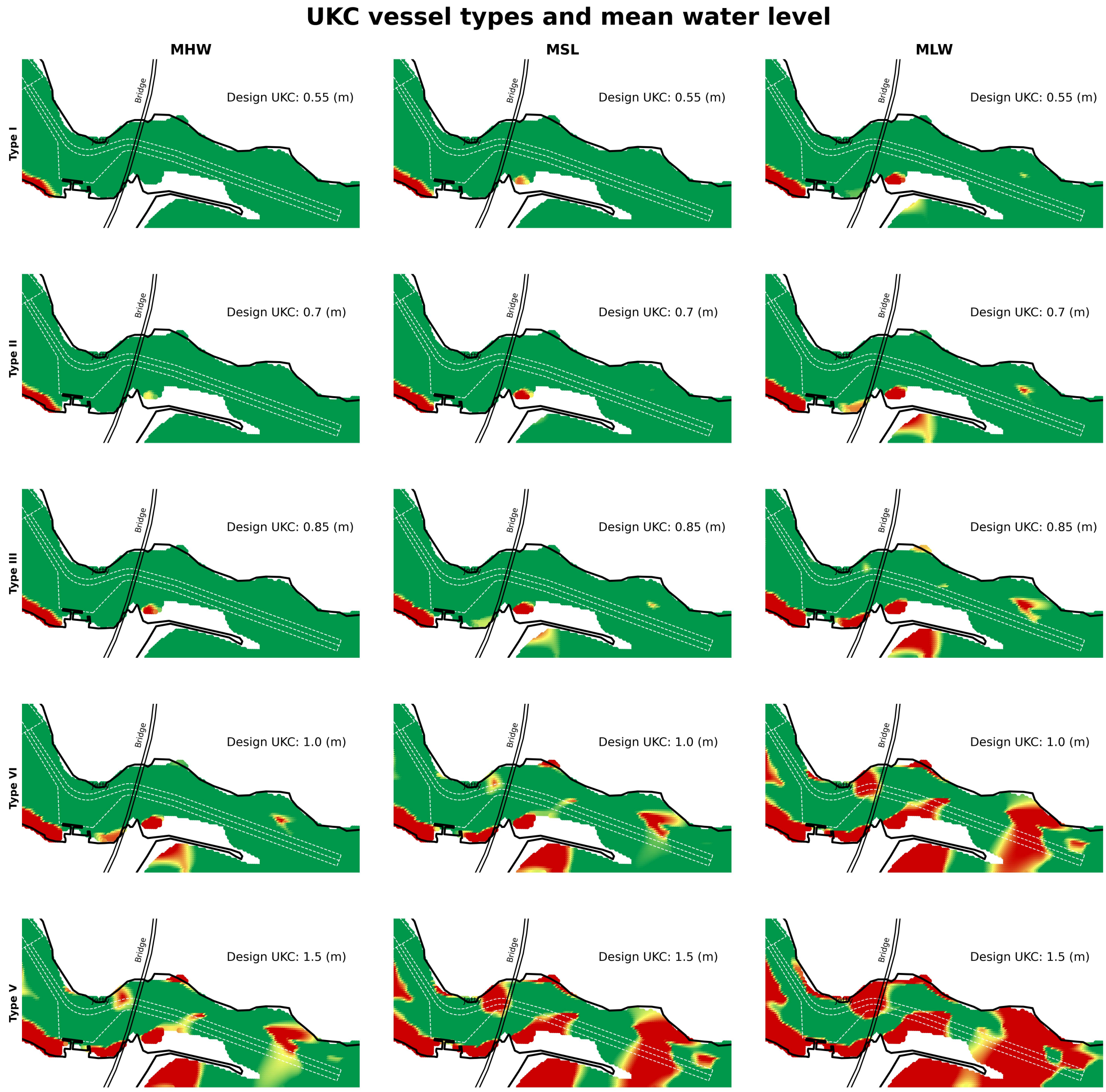


Figure 40: UKC spatial accessibility

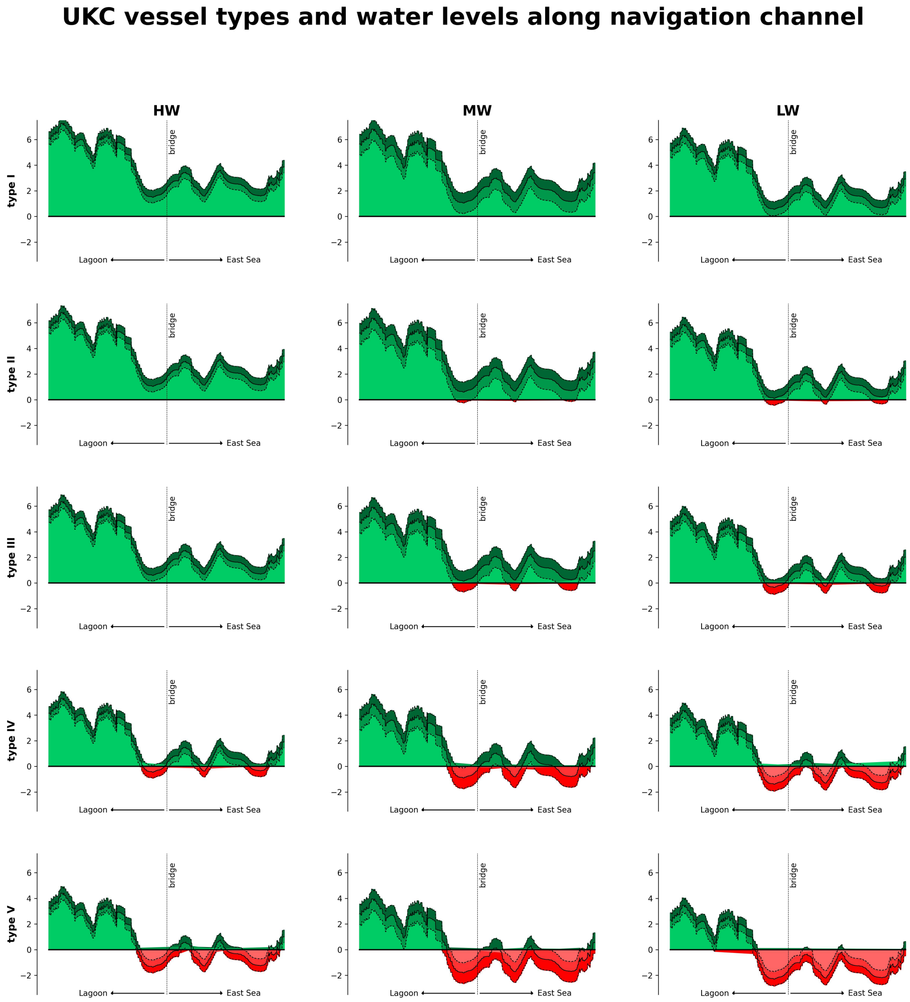


Figure 41: UKC channel accessibility

With this depth assessment, a qualitative determination can be done where and how significant the bottlenecks are.

The draught of the channel

By focusing on the water depth in the current situation, 2021 without extreme conditions, the following results can be extracted from the plots in figure 40 and 41: the vessels of Type I and II together form 50% of the current and future fleet, according to table 16. They are able to enter the channel under all tidal conditions (figure 40). It almost applies to design standards, only for Type II at low water figure 41 shows some red exceedances.

Besides vessels of Type I and II, also Type III is able to enter the channel under all tidal conditions (figure 40). However, for more than 50% of the tidal cycle, Type III vessels can not enter conform design standards, see figure 41 (MSL is more prevalent than MHW and MLW). Based on the future expected fleet mix for the designed storm shelter project KND in table 16, 90% of the vessels up to Type III meet this standard of entrance.

From Type IV up, no vessel can enter the channel during low water, also not with alternative routing outside the designated design access channel. Figure 40 shows this is due to the ebb tidal shoal spread across the channel width near the sea entrance. The situation holds for 25% of the currently registered vessel fleet (table 16). Besides the ebb tidal shoal formation, at MSL for Type IV vessels, the formation of two other shoals arises; north of the breakwater and just west of the bridge, see figure 40.

Type V vessels are the largest vessels designed for in the KND project. The currently registered vessel fleet consists of 25% of such vessels. They are not able to enter the channel for design UKC in all tidal conditions. This includes the highest high water of the confidence interval (1%), as can be seen in figure 41 for Type V during high water at the left side of the bridge. The vessels are most likely to be dependent on alternative routing for all water levels (figure 40). Their only window of entrance is during high water.

In general, it is calculated that based on figure 40, figure 41 and table 16, a minimum of only 5% of daily future visits need alternative routing. This portion of the daily visits needs a minimum of MHW level to enter the channel, disregarding the design standards in figure 41. Similar conditions hold for the future storm shelter design fleet of the KND project.

Except for the ebb tidal shoal, the existing shallow banks inside the channel can be bypassed by alternative routing with a UKC according to the design standards. In figure 40, the depth in the outside bends appears to be deeper than the designated access channel. Overall, there are no vessels that can never enter the channel.

The three downward-facing bump-shapes in the plots of figure 41 can clearly be recognized at the top view plots in figure 40. The bumps represent shoals within the channel. All problems related to water depth occurring, appear in the part of the access channel eastward of the jetty. The existence of shoals is related to hydro- and morphodynamics. Section 6.2 provides an analysis of relevant phenomena in this area, combined in figure 43 to represent the relevant features affecting the channel and to evaluate their complex interactions leading to the problems occurring in the channel. The three shoals that contribute to accessibility problems are numbered in figure 42.

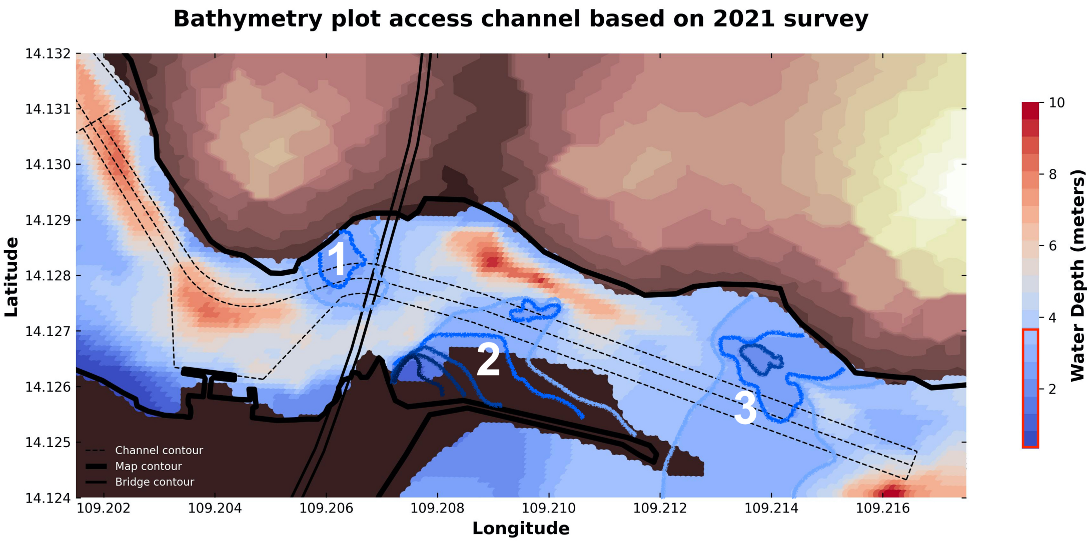


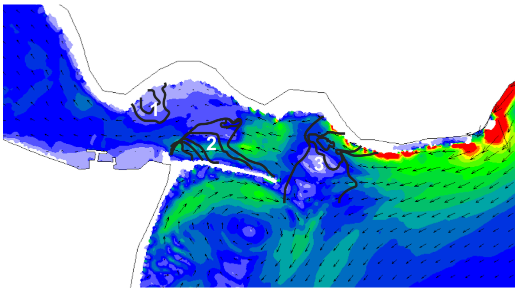
Figure 42: Shallows in access channel at Mean Sea Level. From left to right: shoal 1, 2 and 3.

In general, flow causes erosion and sedimentation due to higher and lower velocities, respectively. In plots (a) up to and including (d) of figure 43, such flow are shown based on subsection 6.2.2 Current. At the most shallow parts of shoals 1, 2 and 3, flow velocities are the lowest in the channel. Shoal 2 continues through the main flow trend line in the channel. Near shoal 2, a decrease in velocities can be observed, especially when stronger currents occur (plot (c) and (d)). So, the flow tends to follow the deepest parts of the channel bathymetry. The deeper area between shoals 2 and 3 shows a significantly increased velocity from the edges of the banks.

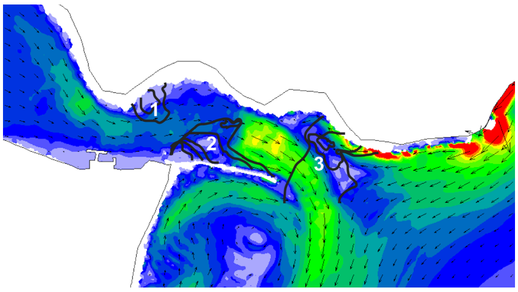
Besides flow, flux' also gives valuable information about morphodynamic processes. Plot (e) expresses a displacement of a cubic metre of suspended water volume per second per metre (m3/s/m). This can also be interpreted as acceleration for positive values and deceleration for negative values. Deceleration is linked with turbulence in fluid dynamics. As a result, sediment distributed throughout the water column will become suspended. In combination with flow velocities, this could result in accretion or erosion. In plot (e) of figure 43 one can obtain the depressions in flux' (deceleration) near the locations of the shoals.

Lastly, the channel is known to struggle with sedimentation issues, see subsection 6.2.3. High NE monsoon waves in December (plot (f) in figure 43) are known to reach the deepest into the channel as analysed in subsection 6.2.2. Waves have a big impact on sedimentation and morphodynamic processes. However, the waves coming from the sea can only reach just behind the bridge, due to the geographical shape of the channel. In this part, the estuary is wave-dominated as stated in section 6.2. It endorses the likelihood that the main morphological activities and complexity are found eastward of the jetty, as was seen in figure 40 and 41. At the lagoon side of the access channel, wave impact is minimal. Therefore current flow by tidal dynamic equilibrium processes are more dominant and naturally maintain the designed access channel via erosion and accretion during high and low tide. Although dredge activities are also required and executed here (see subsection 6.3.2), the concentrated flow trend line through the channel is more likely to sustain longer and naturally, as can be seen in plot a-d in figure 43.

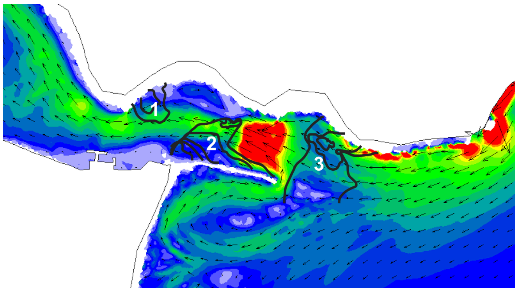
Besides waves, other sedimentation processes also influence the shoals. Especially shoal 3, known as the ebb tidal shoal, experiences deposition from different sources. Subsection 6.2.3 states that south- and northward transport due to monsoons and the asymmetrical shape of the coastline feed this shoal extensively as well.



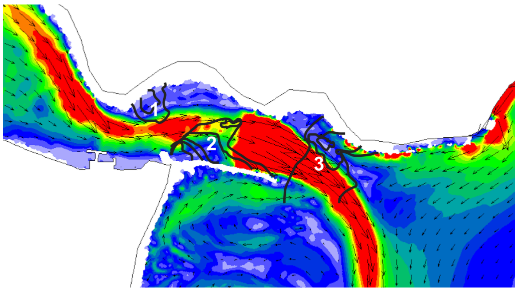
(a) Bathymetry shoals compared to *high tide* and *low velocities* (Section 6.2.2)



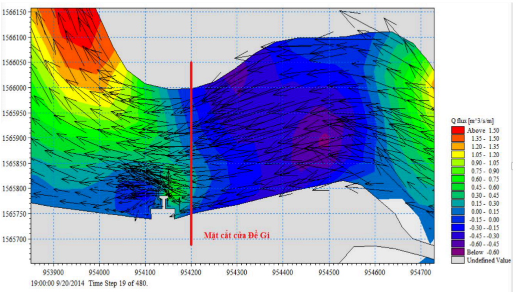
(b) Bathymetry shoals compared to *low tide* and *low velocities* (Section 6.2.2)



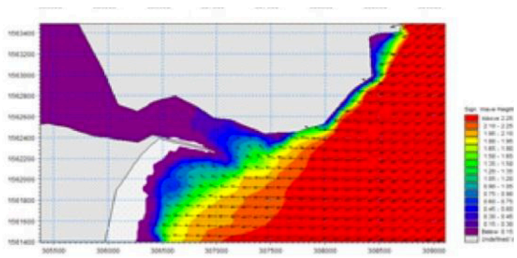
(c) Bathymetry shoals compared to *high tide* and *high velocities* (Section 6.2.2)



(d) Bathymetry shoals compared to *low tide* and *high velocities* (Section 6.2.2)



(e) Flux per meter across channel during rising tide (Section 6.2.2)



(f) Highest wave impact in December (Section 6.2.2)

Figure 43

The impact of climate change

As previously described, it has been stated that Vietnam is one of the "Most Vulnerable Countries" affected by climate change. The impact of climate change will be qualitatively analysed with respect to the depth assessment (figure 40 and figure 41).

As discussed in subsection 6.2.1 within paragraph Climate change, the temperature in Vietnam will increase by 1-3.5 °C. This temperature rise will have an impact on the seawater temperature in the East Sea, leading to alterations in marine ecosystems. For example, these changes can include shifts in the general ocean circulation patterns that influence sedimentation transport around the Đề Gi estuary. The intensity of extreme weather events will also influence the sediment transport. An increase in the intensity of these events will result in more sediment moving around the estuary, potentially leading to more sediment deposition in the access channel and the emergence of shoals. Additionally, the increase of extreme conditions will also lead to heavy rainfall causing more sedimentation depositing in the access channel due to sand slide of the sand dune on the headland, as mentioned in subsection 6.2.3. Furthermore, extreme events can give rise to storm surges which are expected to increase due to climate change, raising water levels in the channel. In the coastal area of Bình Định, it is predicted that the storm surge may rise to 230 cm in the future. While this initially seems beneficial in terms of increasing UKC, it may also create unpredictable and challenging navigation routes for vessels caused by more frequent morphological changes due to larger wave impacts. The IPCC expects that due to climate change, the summer monsoon (SW monsoon) will lengthen meaning that it is questionable if the NE monsoon will still be dominant (see subsection 6.2.3 paragraph Sediment transport). The extended SW monsoon period will result in a longer duration for sediment to move northwards. Questions may arise regarding whether the headland will block a significant part of the sediment, leading to the growth of the ebb tidal delta and potentially resulting in a shallowing entrance area around the Đề Gi estuary. As in paragraph Climate change stated: "MSL rise in Vietnam is likely higher than the global MSL rise". The MSL rise can trigger high coastal erosion processes. The effect of sea level rise can be explained by the concept of Bruun. This rule assumes that the cross-shore of a coastline is in equilibrium with the hydrodynamic conditions. As can be observed in figure 44, the length of the vertical and horizontal lines are approximately the same in both situations (before and after MSL rise), meaning the cross-shore profile shape remains the same respectively. The volume of the sediment that is eroded from the coast is equal to the volume of sediment that is deposited in deeper water (Bosboom and Stive 2023).

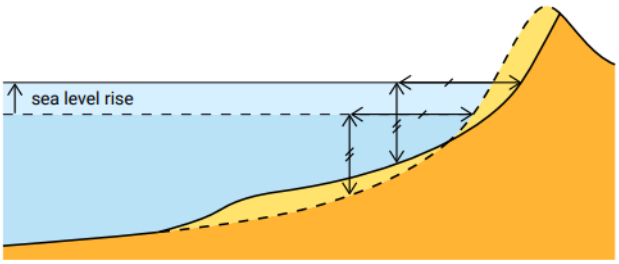


Figure 44: Bruun effect due to rise of MSL (Bosboom and Stive 2023)

An increase in MSL will lead to more coastline erosion in the Đề Gi area. This erosion will result in increased sediment deposits in the East Sea which contributes to the presence of more sediment that can move around the Đề Gi area. Furthermore, the MSL rise may alter current patterns around the Đề Gi area, potentially affecting the depth of the access channel. Finally, the rise of the sea level can also result in greater tidal ranges leading to more dramatically varying water levels between high and low tides.

Mapping the main potential climate change challenges will provide a more comprehensive understanding of how this bottleneck impacts accessibility. The causes of climate change mostly affect the tidal window and the depth where vessels can enter the access channel. Many other aspects will be affected by the causes of climate change. However, this report mainly focuses on the change in tidal window and depth. The tidal window can decrease due to an increase in the tidal ranges.

More rapid changes in water levels may reduce the time available for vessels to navigate through the access channel. Furthermore, the depth of the access channel will also decrease, because of the potential increases of the sedimentation processes in the access channel.

As already mentioned in the previous paragraph, The draught of the channel, vessels of Type I II, III are able to enter the channel at all tidal conditions, see figure 40. However, in the depth assessment of 2021, the UKC in the access channel for vessel Type II applies to design standards, except at low water (figure 41). Due to multiple causes of climate change, the tidal window and the depth may decrease leading to a potential reduction of the amount of vessels of Type II that can always enter the channel. This also applies to vessel Type III. However, there is a great chance that these vessel types can still enter the channel using alternative routing through the estuary. The greatest problem lies in the accessibility of vessels Type IV and V. The depth assessment of 2021 revealed that neither Type IV nor Type V vessels can access the channel during low water. Additionally, vessels of Type V are also unable to enter the channel during mean water. In the future, due to a decrease in the tidal window and depth, chances are that both vessel types can not navigate through the estuary, unfortunately also during high water. The main cause of this is the increase in the width and the decrease in the depth of the ebb shoal due to an increase in sediment transport.

As described previously, the intensity of extreme weather events tends to increase leading to higher wave energy during these events. As stated in the previous paragraph, waves have a big impact on the sedimentation processes. The assessment of 2021 revealed that the waves coming from the sea only reach just behind the bridge which endorses the likelihood that the main morphological activities are found eastward of the jetty. An increase in wave energy due to climate change may lead to the main morphological activities in the future can be found also on the west side of the bridge.

In short, climate change is expected to bring a series of complex challenges to the accessibility of the channel.

6.4.4 Conclusion

To answer the main research question on the current performance of the Đề Gi port and storm shelter system and how engineering methods can be utilized, research from a hydraulic perspective is performed. This chapter has covered content regarding the second research question, which repeats:

> *'How to examine the accessibility of the port and storm shelter in the KND-project, while ensuring a safe, robust, durable and effective system?'*

This research has demonstrated that accessibility can be examined through a depth assessment involving the following components: (1) vessel specifications, (2) water level data with confidence interval, and (3) bathymetry data of the channel area. Evaluating the data from the depth assessment (subsection 6.4.3) along with system analysis of hydro- and morphodynamics (section 6.2), as in figures 40 and 41, provides an indication of the 4 quality aspect on accessibility (section 6.4). For the current situation (2021) of the port and storm shelter design by the KND project, an estimation has been made on the accessibility status. From this the following conclusions can be drawn:

1). Safety is the quality aspect concerning the safety of individuals, vessels and environment surroundings (6.4).

- For 90% (Type I, II, and III) of the expected future fleet mix of the design storm shelter in the KND project, the safety in the channel is well-maintained and feasible under all tidal conditions. Almost complying with design keel clearance.

- For larger vessels like Type IV and Type V, the safety of navigation is compromised, especially during low water conditions. Also, the UKC design depth in the design access channel is not feasible for such vessels during all tidal conditions. Climate change is expected to exacerbate the safety concerns of the larger vessels.
- For Type IV vessels it is expected to enter the channel safely above mean sea level (at least 50
- The remaining 5% of the future fleet mix (Type V vessels) face a more hazardous situation. The normal design access channel may not be accessible for this vessel size, which poses safety concerns.
- Climate change introduces safety risks related to the intensity increase of extreme weather events, higher wave energy, and sediment transport changes that can lead to unpredictable and challenging navigation conditions during storms.

2). Robustness is the quality aspect concerning the functioning of the channel without constraints, with risks of the occurrence of events (6.4).

- The research highlights the high dependency on maintenance of the channel due to the morphodynamic activity. Wave impact conveys morphodynamics, therefore it is most likely the activity of this phenomenon occurs on the seaward side of the channel.
- The design access channel is not located in the deeper area of the estuary. Here, higher flow velocities, based on the results of MIKE21 modelling, seem to naturally deepen the outer bounds of the channel geology. Due to the existence of the bridge, the fairway has been fixed in its current (design) situation where the possibility of sedimentation increases because of lower flow velocities and deceleration of flux'. Therefore, robustness is compromised and dependence on dredging increases.
- The system is expected to show high vulnerabilities after storm events. Storms lead to higher unpredictable wave energy and impact, which possibly increase sedimentation import in the channel. The intensity of these extreme events is influenced by climate change.

3). Durability is the quality concerning the lastingness over time, with risks appearing in future growth and climate change (6.4).

- Growth of influx in future vessel numbers might not necessarily raise issues affecting the depth and durability in normal weather conditions since it does not change the morphology. However, during storm conditions, it is likely that an increase in vessel fleet makes the access channel more busy than usual. Causing possible bottlenecks in higher waiting times and a crowded fairway, causing problems with the quality aspects of safety.
- The research indicates that the sedimentation processes and changing water levels due to climate change can affect the durability of the channel. Research shows that sea level rise leads to coastal erosion or beach retreat (Bosboom and Stive 2023). The calved part moves seaward and balances the system. It may even lead to changes in sediment dynamics. Developments of shoals and sediment dynamics could reduce the channel endurance.

4). Effectiveness is the quality concerning the success of the intended results (6.4).

- Based on the results of the depth assessment, the research suggests that for 90% (Type I, II and III) of the expected future fleet mix the accessibility is effective. The vessels can, independent of the tidal cycle, enter the Đề Gi port and storm shelter.
- Larger vessels (Type IV and Type V) may depend on tidal windows. However given their longer operating periods and the small portion (10%) of the future fleet mix, the impact on economic losses is expected to be minimal.
- The report concludes that the general impact of the effectiveness on the accessibility quality is not significant in comparison to the other quality aspects.

So in short terms, the report's conclusions on the current situation (2021) of the port and storm shelter design by the KND-project related to accessibility can be categorized by the four quality aspects: The safety aspect is of critical concern, mainly on the larger vessels. Their dependence is on alternative routing during high water. The need for frequent channel maintenance due to morphodynamic activity decreases the robustness of the system. For durability, the challenges are very much with climate change and the potential impact on sediment dynamics, which is underlined as very critical by the report. On the other hand, the overall effectiveness of the system appears to remain relatively minimally affected by the identified issues.

During the process of the depth assessment and the research on accessibility in general, uncertainties arose on topics of climate change and extreme events and data availability.

Designing, researching, modelling and making depth assessments all come with a dosage of uncertainties in representing real-world situations. A big factor in uncertainty is the availability of data. As mentioned in section 2.5.1, the design plans of the breakwater construction to mitigate current sedimentation issues, as was proposed in the initial plan of the KND project, were cancelled due to investment shortage. Small budgets make big investments in design solutions more valuable and a higher efficiency is required. The current state of available data on hydraulic conditions seems minimal. Two measurements were carried out in 2012 and 2013 reporting current, waves and water levels. Furthermore, bathymetry surveys were executed in 2012 and 2021. So, data shortage causes high uncertainties in modelling and design and therefore efficiency. Also, severe climate change prospects in Vietnam make designing on data shortage even more tricky.

Besides data availability, the evaluation in paragraph 6.4.3 reveals that the future holds high uncertainties related to climate change and extreme events. It is especially affecting the quality aspect of *Durability*, and on long-term the *Safety*. The present state of available research in the area focuses on the sedimentation issues occurring in the Đề Gi Estuary with nowadays conditions, as sorted out in subsection 6.2.3. This is very useful for a better understanding of the sedimentation processes in the area. Meanwhile, the results in paragraph 6.4.3 on the impact of climate change are rather alarming for future predictions in the area. Vietnam is among "the most vulnerable countries" when it comes to climate change, as predicted by the IPCC models. Especially the intensity of extreme events and sea level rise making coastal areas under great threat. Predictions come with uncertainties in future greenhouse gas emissions, regional climate responses, and the timing and extent of changes. Infrastructure projects in coastal areas involve long-term planning and design, commonly based on historical data and conditions. This might lead to a disconnection between the planning phase and design life, and the rapidly changing climate conditions. A change in hydraulic conditions is likely to affect the sediment dynamics as well, inventing new uncertainties in sediment dynamic causes and design. As mentioned earlier the availability of data and funding problems caused the postponement of solution design for a less silting access channel. Integral designing for future climate change scenarios might be costlier, which emphasizes the importance of thoughtful design and investors. This also underlines the importance of climate awareness for the stakeholders and investors involved.

So, to ensure the four quality aspects of the current situation, by taking the uncertainties into consideration, the following things are suggested. According to this report, the focus should be on safety and durability since these are the most critical, considering the current state of accessibility.

Providing navigation assistance for vessels during storm conditions might help alternative routing for larger vessels more safely and reduce waiting time and queue formation. Also, good communication and protocols for larger ships by introducing tidal windows could reduce the probability of grounding of ships. Safety assurance might have a positive effect on the attraction of other vessels in the area.

Regularly dredging operations seems to solve issues on robustness, in the short term. By injecting the dredged material back into the coastal system will enhance counter beach retreatment, as stated to be a problem in subsection 6.3.2 and might help the system to stabilize more naturally.

To ensure the safety, robustness and effectiveness aspects of the channel in the future, improvements on durability are likely to maintain the quality accessibility. Therefore, a climate-resilient design is useful to make the area more future-proof considering climate change scenario predictions by the IPCC models. Therefore, design parameters based on climate change scenarios are necessary. Monitoring and measurement devices can help the area to act adequately and adapt accordingly to environmental changes. From this, data-driven decision-making operations can be scheduled, such as maintenance or infrastructure improvements.

7 Impacts

This chapter addresses the following research question:

What are the consequences of the port and storm shelter upgrade on the logistical system and on the conditions in the waterway and what impact does this have on the Đề Gi area?

This chapter is built up as follows: first, the effects of the port and storm shelter upgrade will be determined. Additionally, the effects will be evaluated from three different perspectives: (1) network capacity, (2) nautical accessibility and (3) socio-economic development. On top of this, the expected impacts on the stakeholders regarding these perspectives will be derived. These stakeholders are the representatives of the interest of the Đề Gi area from chapter 4.

7.1 Changes by upgrading the port and storm shelter

The KND project final report (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022) dedicates chapter 8 to an analysis of socio- and economic efficiency. It focuses on the 'exploiters of the anchorage area' (the Port authority, the 'user' (the fishing industry) and the 'social community' (residents harbour area). The following section lists the expected and intended effects of the project. These effects are the argumentation to support the necessity of the project.

1. Creating a storm shelter for 2000 vessels contributes to an increase in the number of vessels in the Đề Gi area.
2. Since there is more place in the Đề Gi area compared to the previous situation, vessels have to travel less to find a safe anchorage, reducing time and costs.
3. Due to the impact of storms, one or two ships are damaged or sunk annually. A safe anchorage reduces the risk of sinking and prevents loss of life and an economic loss of up to ten billion VND.
4. When fishing vessels arrive at the same time, particularly during extreme weather conditions in combination with the invariable arrival pattern of the vessels, more congestion at the T-jetty is expected during peak moments.
5. More ships calling the Đề Gi port area impose developments on the land surrounding the lagoon. A higher demand for land area increases the value of land and real estate.
6. A stable rest and storm shelter place will help fishermen to physically and mentally rest from their work, which gives them extra time to work on repairs for example and reduces tiredness, contributing to a safe working environment.
7. If the port is capable of handling larger vessels, it inevitably will attract larger offshore vessels, which expands the exploitation range of fishermen in Đề Gi. This expands the regional market, creating more jobs and improving people's knowledge.
8. A new anchorage area construction project gives room to incorporate environmental protection, aquatic resource protection and security of seas and islands in the design.
9. Fishermen will feel more secure sailing further offshore because they know when needed they have a safe space in the storm shelter available.
10. More vessels daily and during storm imposes more organisational work for the port authority. Stronger guidance and regulations are needed.
11. Professionalisation of the port requires professionalisation of the fishing industry. Simultaneously fishermen will demand a professional port authority.

12. The port and related activities will grow due to the urbanisation and tourist development in the surrounding area.
13. Agricultural land, forestry and residential areas have to make space for the port development (including relocation). Financial compensation and incentive is awarded.
14. People working in agriculture are supported to a career change and get educated to work in the fishing industry.
15. Floating aquaculture is strongly encouraged to relocate to other areas in the Đề Gi lagoon so that they don't affect the project construction and future exploitation.
16. A change in vessel fleet mix (including larger and specialised vessels).

7.2 Consequences and Impacts

The above changes of the upgrade will affect the Đề Gi area in different aspects. This section will provide an analysis of how these consequences affect the stakeholders from the perspectives of network capacity, nautical accessibility, and socio-economic development.

7.2.1 Network capacity

Out of all the outcomes of the KND project, three alterations have the potential to directly impact the network usage in the Đề Gi area.

First of all, the creation of storm shelters for 2000 vessels contributes to an increase in the number of vessels in the Đề Gi area. This means that the Đề Gi port becomes more attractive for fishing vessels from other regions, the guest fishing vessels, for sheltering and trading activities. This increase will directly lead to a rise in the amount of goods that have to be transported through the Đề Gi harbour and indirectly also to an increase in the amount of traffic from and to the harbour in general. From the traffic network analysis section 5.1, it is observable that the current traffic network has limited capacity left, especially around the harbour. When the amount of traffic increases generally, traffic congestion in the network is unavoidable.

The second effect of the upgrading of the port and the storm shelter concerns the simultaneous arrivals of the vessels. When fishing vessels arrive at the same time, particularly during extreme weather conditions in combination with the invariable arrival pattern of the vessels, more serious congestion at the T-jetty is expected during peak moments. Due to limited harbour storage capabilities and on-board storage possibilities, the simultaneous arrivals of the vessels also lead to the simultaneous arrivals and departures of the transport vehicles at the harbour. Therefore the traffic network of the area, especially the surrounding area of the Đề Gi harbour, will affect the drastic increasing of traffic during these peak moments. Based on the traffic network analysis in subsection 5.1.4, it becomes apparent that the traffic infrastructure around the harbour is of low quality. As a consequence of the simultaneous of the harbour's traffic, heavy traffic congestion during the peak periods is expected in the area.

Finally, the KND project also indicates an increase of port and related activities due to the urbanisation and tourist development in the surrounding area. The overview of the future land use in figure 16, indicates that the urbanisation and the tourist developments take place widespread over the whole area of the Phù Mỹ and Phù Cát districts. The growth of the port and related activities, as a consequence of the KND project in combination with the urbanisation and tourist development visions of the area, will lead to an increase in the traffic network for the whole area on a large scale.

In short, the upgrade of the port and storm shelter area will enlarge the transport demand in the transport network of the Đề Gi area on both small and large scale. The effects of this increase will be experienced directly by both residents and traffic participants in the area, especially the stakeholders that have direct relations with the harbour such as residents in the surroundings of the harbour and the transporters of the harbour's goods.

With the current state of the traffic infrastructure without any future improvement and development, these stakeholders will be negatively affected by nuisance and overloaded road networks. However, with the infrastructure development visions of the local authority, the critical components of the road traffic network will be tackled. As a result of this development, the mobility of the area will be improved and thus more attractive for more investments in the area of Đề Gi. Indirectly, this leads to more fruit of life for the proximate people and thus more tranquil neighbourhood due to less rat-running and better alternatives.

7.2.2 Nautical accessibility

The changes in upgrading the port and storm shelter, mentioned in subsection 7.1, will affect the nautical accessibility. The main primary and secondary consequences and impacts are described in this subsection.

There are three primary consequences that will impact nautical accessibility. Firstly, the creation of a storm shelter for 2000 vessels will increase the number of vessels in the Đề Gi area, leading to more vessels navigating through the access channel. Furthermore, there will be a change in the vessel fleet mix. As described in section 6.3, larger vessels will navigate to the Đề Gi harbour, resulting in a greater vessel draught. Finally, the third consequence of the upgrade is the relocation of floating aquaculture.

These primary consequences give rise to secondary consequences. The first and second primary consequences, the increased number of vessels and the larger vessel draught will necessitate new or modified design requirements for the access channel. Failure to adjust the access channel will have negative impacts on various stakeholders and the reputation of Đề Gi. Additionally, the first primary consequence will lead to more congestion in the access channel due to the increased number of vessels. Finally, the third primary consequence, relocating the floating aquaculture, will create more space for vessels to navigate through the access channel.

Assuming there will be adjustments made to the access channel and measures to reduce chaos, the most impacts are expected to be positive. Two secondary consequences, the adjustment of the access channel and the increased space within the channel, will enhance the safety of fishing vessels and fishermen. However, if the access channel is not sufficiently expanded to handle these two consequences, it poses risks to the safety, robustness and overall effectiveness of the channel. Safety risks include an increased likelihood of grounding incidents and collisions, leading to concerns for the safety of the fishermen, the vessels and the surrounding environment. But also more fishing vessels from other locations in Vietnam will increase. These fishing vessels do not know the Đề Gi area very well which might induce safety issues if no measures are taken. Robustness risks involve vessels being unable to enter the access channel and risks to the overall effectiveness include ensuring that the channel remains capable of successful operations and the intended results are not compromised. The access channel must be sufficiently expanded, so the need for frequent maintenance might increase.

Fishermen are a very important stakeholder that will be impacted by these two secondary consequences. Personal safety and subsistence security of fishermen will be improved when the access channel is adjusted. This safety and security increase for fishermen is particularly during extreme weather events. Knowing that there is a safe space in the storm shelter, in case the fishermen need it, they might be more confident to sail farther offshore. As a result of this safety feeling, fishermen might be more prone to find new fishing spots. Furthermore, fishermen have to travel less to find safe anchorage, reducing time and costs meaning that fishermen are able to spend more time on their fishing activities, which may increase catch and revenue.

The second secondary consequence, the increased number of vessels, will lead to more chaos. More restrictions and guidance are needed throughout the access channel. The impact of this change will mostly affect the Đề Gi's port authorities because they will experience an increase in responsibilities. They have to manage more vessels, especially during a storm.

The third secondary consequence, more space in the access channel will not only increase safe navigation for fishing vessels through the access channel but will also give uncertainties for the floating aquaculture business.

The consequences of upgrading the port and storm shelter will lead to a higher demand for improved accessibility, including adjusting the dimensions of the access channel and professionalisation of the port authorities. The impact on the aquaculture industry is negative, but the impact on fishermen will be positive. In general, if the nautical accessibility is improved, the reputation of the Đề Gi port and storm shelter will be better. A better reputation will stimulate the economic growth of the Đề Gi area.

7.2.3 Socio-economic development

The upgrades of the port and storm shelter will impact socio-economic development in several ways.

The increase in the number of vessels in the storm shelter will result in more trading activities in the Đề Gi area, leading to more job opportunities, which is good for the local population. More jobs will contribute to the socio-economic development of the Đề Gi area with respect to poverty reduction and economic growth.

Additionally, since there are more sheltering places in the Đề Gi area compared to the previous situation, vessels have to travel less to find a safe anchorage, reducing time and costs. Fishermen are very important stakeholders that will be impacted by the changes in the development of the Đề Gi area. Personal safety and subsistence security of fishermen are improved by increasing the capacity of the storm shelter (capable of hosting 2000 vessels), which is explained in the reasoning of reducing chaos in the access channel. The mentioned reasoning can also be applied in this specific case and is going to result in a boost in productivity for the fishing industry.

Due to the impact of storms, one or two ships are damaged or sunk annually. A change of a safer anchorage port and storm shelter reduces the risk of sinking and prevents an economic loss of up to ten billion VND for fishermen whose ship was damaged. This all will contribute to economic growth, but it mainly improve the healthcare of the fishermen leading to an indirect increase in the well-being of the local society.

A change in an increase in the number of vessels calling in the Đề Gi area will drive developments in the surrounding land, leading to a higher demand for land area and increasing the value of land and real estate. This, in turn, will contribute to the overall economic growth of the Đề Gi area.

The upgrade of the port and storm shelter will result to that the port being capable of handling larger vessels. These will contribute to the socio-economic development with respect to education purposes and economic growth. Education purposes include an enlargement of people's knowledge.

A new anchorage area construction project gives room to incorporate environmental protection, aquatic resource protection and security of seas and islands in the design. Protecting the environment can lead to the provision of ecosystem services, such as improved water quality, which benefits the local population and reduces health-related expenses. Also, it will help by sustainable development for the area.

Furthermore, more vessels, daily and during a storm, impose more professionalisation of the port authority. Stronger guidance and regulations are needed. The impact of this change will mostly affect the Đề Gi's port authorities because they will experience an increase in responsibilities. They have to manage more vessels, especially during a storm. Due to an increase in the number of vessels, more regulations and restrictions are needed to secure safety in the Đề Gi port and storm shelter. Furthermore, the port authorities might have to improve their services, including communication devices, monitoring devices and safety instruments. Professionalisation can contribute to institutional development. Rules, norms and procedures are established which will improve economic and social interactions.

Agricultural land, forestry and residential areas have to make space for the port development (including relocation) given that a financial compensation and incentive is awarded. This change will have both positive and negative impacts on the socio-economic development of the Đề Gi area. The positive contribution is that the economic growth in the region will be stimulated by the development of the port. This leads to more jobs and business opportunities and thus to an increase in the local GDP. However, the need to make space for port development may lead to the displacement of local residents, disrupting their livelihoods and communities. The conversion of agricultural land for port development can reduce local food production, potentially leading to food security issues.

Finally, with the new developments, it is expected people working in agriculture will be supported to a career change and get educated to work in the fishing industry. Education and training for the fishing industry can lead to improved skills among the local population, enhancing their employability and potential earnings. This also provides new income sources for individuals, potentially improving their living standards and overall well-being. Furthermore, the transition of individuals from agriculture to the fishing industry can diversify the local economy, reducing vulnerability to fluctuations in a single sector. This could lead to a reduction in unemployment rates, contributing to greater socio-economic stability in the region.

7.3 Conclusion

The consequences of the upgrade of the port and storm shelter system in the Đề Gi area are analysed from multiple perspectives, including network capacity, nautical accessibility, and socio-economic development. The port and storm shelter upgrade brings about numerous consequences and adjustments, the overall impact on the Đề Gi area is expected to be positive, fostering socio-economic development, enhancing safety, and opening new opportunities for the local population. However, effective planning and infrastructure development will be crucial to realizing these potential benefits and mitigating the associated challenges.

8 Conclusion

This chapter summarizes the findings of the research and answers the main research question about the current performance of the Đề Gi port and storm shelter system in its future potential. The research is based on three supporting parts, represented by sub-research questions.

The first subquestion addresses the performance of the current logistic service network from the perspective of a future vision by responsible authorities and engineering methods to verify this. This research provides a first-hand understanding of the logistic network, assessed qualitatively in the rationale of the 4(+1) step model methodology. Analysis of the current network capacity is the basis for this Traffic modelling and approached by field observations. These analyses relate aspects of patterns in the Đề Gi harbour, (goods)transport vehicles, the traffic network, the land use of the area and the demography within the study. Although the research is based on self-collected data and single-moment observations due to a shortage of existing data, the analysis still provides several key insights into potential bottlenecks of the current system. Also, future results are evaluated:

- Several connections between the local fish markets and the harbour have very poor transport infrastructure. These observations might result in low effective local fish transportation.
- Lack of traffic information and conditional driver behaviour, rat-running occurs in several urbanisation roads around the Đề Gi harbour. This leads to insufficient traffic distribution in the network and ineffective use of the intended infrastructure.
- Road connections around the harbour are vulnerable and likely to be overloaded during the peak moment.
- New constructed network infrastructure is likely to cause capacity drops at new and existing road connections. Resulting in an increased probability of overloading existing traffic network connections.
- The ambitions of growth in urbanisation and tourism by the local authorities will undoubtedly lead to an increase in traffic intensity in the area. Forming a threat for the low capacity connections of the traffic network in the area.

From the outcome of the analysis, the research learned that for reliable and consistent results on intensity and capacity issues data collection is decisive to provide a quantitative verification. Since quantitative data is missing in the current state of existing research in the area, the second part of the subquestion describes the verification philosophy of the 4(+1) step method, see figure 17. This type of transport model is used since it's a primary tool to test the capacity. Input variables for the model are zonal data for in- and external zones, the traffic demand per origin-destination pair (OD pair), the distribution of the modal split for the fish transport from the Đề Gi harbour and finally the travel time per travelled route as the impedance of the assigned traffic. Finally, the ultimate traffic assignment of All-or-Nothing assignment is expected to raise the quality of verification of the network capacity of the future.

The second subquestion addresses the accessibility of the port and storm shelter. The research collects and analyses information and data on hydraulic conditions, morphological conditions and the functioning of the current nautical access channel. This analysis is used to create a methodology for assessing the current state of accessibility of the fairway. A risk analysis showed that based on the four quality aspects of accessibility the main issues come with a vessel draught. Therefore the research uses a Python-based depth-assessment with input parameters on vessel UKC, bathymetry data and water level data. The output of the code provides plots in which both a spacial and longitudinal section perspective is represented. It includes results in design depth and keel clearance for each vessel type and water level. The method is made useful to examine the accessibility with an integral evaluation of the plots together with the analysis of hydrodynamics, sedimentation causes, climate change and extreme events. Regarding the four accessibility aspects of safety, robustness, durability and effectiveness, the following key outcomes are found:

1. The **Safety** is of critical concern, especially for larger vessel Types. For these vessels safety of navigation is compromised during low water conditions, with potential safety risks worsened by climate change.
2. The **Robustness** of the system is compromised by the high dependency on dredging maintenance, influenced by sedimentation and an unfavourable location of the fairway. High vulnerabilities are expected during storms.
3. The **Durability** is mainly affected by the alarming climate change prospects for Vietnam, which can lead to changes in sediment dynamics and intenser storms, potentially reducing the channel's durability.
4. The **Effectiveness** remains minimal affected by the results of the depth assessment. With 90% of the expected future fleet mix having effective accessibility.

These findings underline the critical importance of action on safety and durability issues. Especially in perspective on the predictions of future climate change conditions and the uncertainties in the availability of data, a climate-resilient design is desirable.

The third sub-question addresses the impact of the port and storm shelter upgrade on the Đề Gi area. First, several consequences of upgrading the port and storm shelter are derived. The main consequences with respect to the network capacity and nautical accessibility are:

- On the logistical system, the upgrade of the port and storm system results in an increase in the traffic intensity of the traffic network.
- On the nautical accessibility, the upgrade of the port and storm system results in a change in fleet mix and an increase in the number of vessels through the access channel.

These consequences will have the following impacts:

- Due to the increasing traffic intensity in the traffic network, more attention is required in the improvement of the traffic infrastructure in the Đề Gi area. This leads to an advancement in mobility and also in the attractiveness of the area.
- Due to the change in fleet mix and the increase in the number of vessels, there is a need for new or modified design requirements for the access channel. Improving the accessibility of the access channel will enhance the safety of the fishermen, the vessels and the surrounding environment.

Ultimately, these impacts will have a significant influence on the socio-economic development of the area. The upgrade has the potential to stimulate economic growth, enhance educational opportunities and increase the investment attractiveness of the Đề Gi area. However, it's important to note that the positive effects of these three aspects are dependent on the implementation of necessary adjustments in the logistical system and nautical accessibility.

Coming back to the main research question on the performance of the storm shelter system and its engineering methods, this question is repeated as follows:

> 'What is the current performance of the Đề Gi port and storm shelter system, and how can engineering methods be used to assess its potential for future growth within the broader context of socio-economic development?'

The current state of the Đề Gi area with respect to transportation of goods, is that without improvements, the capacity of the network is insufficient for future growth. However, the implementation of the development visions of the local authorities should resolve the current bottlenecks in the logistic services system of the Đề Gi area. The current nautical accessibility operates at 90% effectiveness and it is not consistently safe in all tidal conditions. In the future, the accessibility is expected to be reduced in its durability, due to the vulnerability of Vietnam's coast to climate change. Where especially, sea level rise and extreme storm events have a likelihood of negative morphodynamic processes. Historical design data might no longer be synchronized with design parameters of the future.

The engineering models considered in the research, provide a way to quantify the measures that are required for future growth. The inland transport capacity, assessed by the 4(+1) step methodology, dictates what the system is able to process. Together it holds the potential for the future growth of the area. A comprehensive system analysis, including the topics of (1) climate change, (2) hydrodynamics, (3) morphodynamics and (3) current and future conditions of the access channel, and depth assessment provides insights into future nautical accessibility challenges to enhance the future growth of the Đề Gi area. These methods helped investigate the future socio-economic impacts that the port and storm shelter upgrade will have on the Đề Gi area. Although the port and storm shelter upgrade has many consequences and adjustments, the Đề Gi area will mainly benefit from it since it fosters socio-economic development, improves safety and provides new opportunities for the local community.

9 Discussion

This chapter facilitates a nuanced understanding of the research conclusions. First, the acknowledgement of the inherent research limitations is discussed. Subsequently, a set of recommendations and follow-up research is proposed based on the outcomes in chapter 8. This can function as a guide in future progressing aspirations and to mitigate the stated limitations.

Also, this chapter offers a contribution to the presented outcomes of the research and represents it in a broader context of the available knowledge domain. The research helps to provide a stepping stone for following research or practical executions.

9.1 Limitations

As this research serves as the initial step in exploring the area's potential, it experienced constraints along the way. In this section limitations or challenges are discussed that affect the results of the research project to provide insight into where improvements can be found. The main limitations are treated below.

Data
One of those main sources of limitations comes with the availability of sufficient, understandable, unbiased and workable data. The hydraulic conditions of the Đề Gi region have been studied before, but lack quantity. Yet, in all research so far in the area, two data sets of only five days are used. This leads to uncertainties in data-based research purposes like designs and sedimentation modelling, and therefore to uncertainties in quantifying accessibility. Also, data on storm conditions are limited. Besides hydraulic conditions, data availability on dredging activity is not available. This data is very relevant for a better understanding of the dynamics of the channel's bathymetry, since it distinguishes the natural morphology from the human interference. In collecting data for the accessibility study, the project team was limited by time in the field and equipment. The team was only able to conduct field observation with limited sources. Also, for reliable data, measurements over a longer period should be executed. This was not feasible within the time of the project schedule.

Data for the study on the network capacity is even more scarce. The data sources are mainly based on plans and visions from governmental bodies, but there is no availability of actual field surveys, statistics or user experiences. Since the available time, budget and skills to carry out field surveys within the project are limited, some part of the research and following advice is based on educated guesses. However, the network capacity study still relies on collecting this data. Collection has been carried out by the research team.

The ability to collect data is part of the availability. During the field trip observations in the Đề Gi port, its port authorities reacted suspiciously and defensively towards research works. The indurate and tense relationship between the research team and the port authorities resulted in the port authorities sending the research team off all times, when conducting interviews at the harbour area. Therefore the team was limited to only approximately four interviews each morning. Interviews are useful for validation of the observed behavioural patterns within the port, but also for the stakeholder analysis to investigate the impact of future developments and impacts of stakeholders. Limiting the comprehensive understanding of stakeholder relations in the area.

Furthermore, this prevented the team from receiving data on registration and entry fees for vehicles entering the port. This limits both the quantitative significance of the modes mix but also the distribution over the zones. Together with problems concerning the observing equipment the team was unable to observe the harbour for a full continuous 24 hours. This limits the determination of peak moments over the day. Therefore the research mainly relies on educated guesses instead of statistical data.

Apart from interviews, road measurements have been taken in limited locations where it is safe to do so. Due to the high vehicle intensity on the road, the measurements had to be taken swiftly and might include a higher error margin. Since the network capacity study was designated to self-collecting data, time limits in the field caused bigger assumptions and estimates.

For example, the merging and splitting of communes with local market(s) into zones with a single market as centroid, gave rise to merging and splitting of population data. This data is only available on the level of communes which led to educated guesses on the population distribution within the communes, where the markets of significance are used. This was based on both local accounts from interviews and information found online, so the significance can not be guaranteed. Another example due to time limitations is the reduction of actual road section numbers. This approach consolidates multiple changes in the road into a single section.

The lack of data limits finalizing the last step in the basic 4-step model. More input as of now available is required for the program to be able to run.

The understandability of data led to problems that limited the progress of the research. Almost every data source is written in Vietnamese, which the majority of the project group doesn't master. Modern technology allows for a rather good translation, but it doesn't work for every information source and it isn't always as good as it could be in academic English. Besides, translation simply costs extra time and effort. A possible result is that data could have been misinterpreted at some point. Also, in the hydraulic available data sources, some unclarities in data processing of bathymetry data in the Vietnamese language edge the interpretation abilities of the research team.

Besides data availability, understandability and validity, data also has to be workable. During the research, the provided data was sometimes formatted differently than what the research group was used to. Making it time-consuming to comprehend and workable. With help from data authors at Thủy Lợi University, some data was able to be converted to familiar formats.

General limitations encountered
Additional limitations stem from the defined scope area. The consequences may extend beyond the confines of the Đề Gi area, as the research predominantly pertains to the access channel and network capacity and may not encompass broader regional, national, or global effects that could be influenced by the upgrade. The scope area therefore might limit the comprehensive understanding of its full implications.

In the absence of dedicated research specifically addressing the project's impacts, comprehensive and in-depth research is difficult, potentially restricting the assessment of the complete impact to surface-level aspects while leaving more intricate consequences unexamined.

Numerous factors of interest remain undisclosed to the research team, as these elements are perceived as potentially interrelated components within the research context. Illustrative instances encompass the effects of deforestation within the region, the effect of a permeable breakwater, and the consequences of climate change on morphodynamic processes occurring in the channel.

9.2 Recommendations

For the benefit of the future research, this study has derived advises on follow-up researches. From the limitations one can find that data is extracted from all kind of sources and is not available easily. Therefore, it is recommended to collect the data centrally in a structured matter, to make it uniformly accessible, workable and understandable for current, as well as future research purposes. Generally speaking an expansion of the current dataset with more measurements and investigation on the network capacity, hydraulic conditions and socio-economic structure is recommended. A selection of recommendations following the network research are:

- Assess the capacity of the surrounding road infrastructure.
- Perform a thorough and long term vehicle count on the roads in the De Gi area, potentially utilizing the existing traffic cameras.
- Obtain vehicle counts by traffic modes at the harbour entrance, including timestamps and registration of the district origin of the vehicles.
- Secure official access to the harbour premises by the Port Authority and obtain registration data and fee administration of vehicles and vessels entering the port.

These points will contribute to a better examination of the network capacity. Upon collecting this data, it is recommended to implement a data-driven approach to analyze the capacity, using the defined conceptual 4-step model in the research.

Considering the hydraulic conditions, further research is recommended for:

- The permeability of the breakwater. Sedimentation is observed to undermine the breakwater due to porosity. Permeability is something not included in the performed flow models, MIKE21.
- The influence of construction of the bridge on the tidal prism, how it effects the sedimentation dynamics and the channel and lagoon stability on the long-term.
- The influence of construction of the bridge on bathymetry variations, in comparison to pre-construction. This provides useful analysis, since the presence of the bridge changed the fairway location. The accessibility assessment of this research is based on bathymetry data before construction.
- Studying the execution of dredging activities in the access channel, including it's frequency, location, timing, goal and expenses. To gain more distinguished insight on the morphology changes by natural or human activity.
- The effects of sea level rise on sedimentation processes in coastal areas with an emphasis on it's potential impact on channel accessibility.
- Extension of the current available data in the region. Periodic measurements on waves, water levels and currents. Especially, wave measurements during storm conditions.

Overall speaking, this data will help in formulating the argumentation on the necessity to intervene in the current system. The current argumentation is considered to be rather insufficient by the research team. A thorough understanding of the problem is necessary for the decision making process when pursuing a safe, robust, durable and effective design.

As described in the section on limitations, it is difficult to assess the real impact a project as this has on the area. Engineering methods might not be sufficient to fully grasp the socio-economic structure, therefore a study on the relation between the port and the local community by researchers experienced in socio-economics is recommended.

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A Timeline

This appendix gives a overview of the rough planning of the project carried out by the project team.

Phase	Milestone	Task	Duration
Preparation	Project set-up	Project scope and goals	1,5 weeks
	Literature review	Review on the research area Review on the national and regional visions Review on design of KND project Đề Gi	
	Research proposal	Define research objectives and research questions Develop research methodology and planning	
Execution	Literature studies	Conduct a study of the national, Provincial and communal development plans Study the coastal systems of Vietnam and the specific situation of the De Gi area Study the current and future conditions of the access channel Study General notes on construction planning of Phù Cát and Phù Mỹ	5,5 weeks
	Fieldwork	Define and interview stakeholders Map traffic network and collect information on road sections Conduct vehicle count with modes, registration district and timestamp Define the current spatial planning Define current logistical chain in the Đề Gi port. Observe hydrodynamics and morphodynamics along the coast line of the Đề Gi area	
	Data processing	Convert road section observations to capacity Convert vehicle counts to peak hour factor, distribution and mode choice. Merging different data sources to usable model	
	Data analysis	Power interest diagram 4(+1)-transport model philosophy Dept assessment of access channel and find multiple bottlenecks Assessing the effect of climate change Assessing impacts of the project	
Wrap up	Delivery	Writing the final report Present at Thủy Lợi University	3 weeks
	Evaluation	Evaluate the final results with feedback of the presentation at Thủy Lợi Evaluate the project team management	
	Final delivery	Present at TU Delft	

Table 17: Detailed research timeline

B Stakeholder analyses

Within the Đề Gi area, many groups are affected by the enlarging of the Đề Gi port. All these groups will be stakeholders in the project. A list is made of all stakeholders for the project in alphabetic order.

Bình Định province
On a provincial level, the acting authority is from the Bình Định province. This is one level lower than the Ministry of Agriculture and Rural Development, however, the priorities of the province are in line with the ministry. The province has the highest economic output of the south central Vietnam coastal region. This is mainly due to the strong primary sector in the province among others: agriculture and fishery. The province wants to enlarge its economic potential without harming the existing economic motors. To increase the economic competitiveness of the provincial capital Quy Nhơn, the fishing harbour has to make room for a more economically important deep sea harbour. To continue fishing activities within the province, relocation to other locations within the province is deemed necessary. The province, therefore is involved in the enlargement of the port capacity of Đề Gi. For the province, however, it is not important if Đề Gi will expand or if another fishing port within the province will do so. As a result, the province is less involved at the lower levels of government but plays a more prominent role at higher governmental levels(Bình Định n.d.).

Coastguard
The Vietnamese coast guard has been tasked with the responsibility of safeguarding maritime safety within the territorial waters of Vietnam. To fulfill this role, the coast guard maintains a fleet of variously sized ships strategically positioned along the Vietnamese coastline. Notably, within the Đề Gi estuary, there are multiple small vessels stationed, signifying their critical role within a small segment of Vietnamese waters. In this area, these vessels may serve as the first response, preceding the arrival of coast guard ships from further away. Therefore, it is important for the coastguard that these ships have unhindered access to the sea at all times. The coast guard is directly connected to the Vietnamese government and can have a big impact on projects taking place within Vietnamese waters via this connection (Cảnh sát biển Việt nam n.d.).

Fish processing industry
The fish processing industry is the biggest purchaser of Đề Gi Fish. The industry makes contracts with the fishing fleet about the amount of catchment and the locations where the fish should get to land. More than half the tonnage of all fish in Đề Gi is expected to make its way to a fish processing factory. Therefore, this group is very influential and has a big interest in the good handling of fishing vessels and the logistical chain.

Fishermen
Fishermen are individuals working in the fishing industry, commonly operating on fishing vessels of various types. Fishing is the main source of income for these people. Depending on the type of vessel they work on, they either fish for a maximum of 1 day close to shore or stay at sea far offshore for up to several months. Every fishing vessel has a registered home location, the Đề Gi port is one of these locations. Fishermen preferably unload their catch at their home port, since often they live close to this location. Besides, vessels from other ports further away may use the Đề Gi port as their unloading port, since it's the closest to the fishing grounds. Furthermore, Đề Gi is a storm shelter. In case of a storm, vessels leave the sea and seek shelter at the nearest safe location. The fishermen have a high interest in the well-functioning of the port and storm shelter, however, their individual influence on the port operations is limited.

Floating aquaculture
Floating aquaculture are stationary fishing farms located on open water in the lagoon and access channel. The farms are constructed of floating elements with nets or lines for breeding pelagic fish or shellfish. Full-grown fish is sold in the same way as fish caught with fishing vessels. Work on the fishing farm is the main income of employees, whereas the fishing farm owners depend on a good sale of fish. The floating aquaculture is related to the port because they use the sales market, marine services and hydraulic shelter properties. Thus, they depend on the operational and physical properties of the port. The influence on the port is assumed to be small, since observations have shown that they are only present in this location for a couple of years.

Government
The Vietnamese Government, functioning as the executive branch of the National Assembly, holds the authority to execute governmental powers and constitutes the paramount administrative entity within the Socialist Republic of Vietnam. The Government maintains responsibility towards the National Assembly and is required to present regular reports to the National Assembly, its Standing Committee, as well as the State President. Within this context, the government places a paramount emphasis on the sustaining of the Vietnamese fishing industry. The Đề Gi port's size is insufficient to warrant attention. In the event that the port aligns with the government's fishing industry objectives, there is no anticipation of direct government involvement. Nevertheless, it's essential to recognize that the government holds the ultimate authority and retains the capacity to terminate the project at its discretion.

Local markets
Local markets receive fish from Đề Gi fishing harbour. They do want to keep receiving this fish at the same time as before the KND project. Therefore, it is important to them that while overall vessel intensity increase in the harbour, this does not lead to competition between contracted and non-contracted fishing vessel during the morning peak hour, so the current supply chain of fish receiving on time for the morning markets does not get affected.

Local salesmen at port
Local salesmen at the port are people doing business directly at the T-jetty of the port where they buy (mostly a full) catch straight from incoming vessels in a bidding process competing with other salesmen. They resell goods to individuals or sub-salesmen. The trade of fish is their main occupation and source of income. They depend on the supply of fish by fishing vessels, unloading catch at Đề Gi and the demand for fish from locals and/or sub-traders. Conversely, the attractiveness of the port for fishing vessels depends on the presence of sufficient salesmen willing to pay enough for the catch. Their individual level of impact on the port system however is low, since they work in a competing market where their position is replaceable.

Marine services
Marine services represent the people and businesses that support the port operations and fishing industry with the necessary supplies. A few examples are ice factories, diesel fuel points and shops that sell fishing equipment. These marine services are physically close to the port or on the water in the port. The port and the presence of fishing vessels are the root of their existence. Therefore, they depend strongly on the functioning of the port. Conversely, the attractiveness of the port for fishing vessels partly depends on the presence of marine services, since without marine services the port cannot function. The number of suppliers in diesel and ice is limited, giving them some influence on the daily port operations.

Ministry of Agriculture and Rural Development
One of the eighteen ministries of the government of Vietnam is the Ministry of Agriculture and Rural Development which can be seen as the highest level of authority within the country of Vietnam. The Ministry is responsible for rural development and the governance and care of the

agriculture industry, including aquaculture, in Vietnam. The interest of this actor is stated in the governmental vision to grow on economic grounds as mentioned in section 2.1 and in order to achieve this viewpoint another governmental plan is introduced (section 2.2). This viewpoint entails for example improving productivity and quality and additionally the port and shelter conditions. Therefore, this stakeholder has a high interest in the system of the Đề Gi area while ensuring a high level of power that can be used.

On land aquaculture
Within the scope area, many land acres are used for on-land aquaculture. This industry is supposed to partly replace the reduction of the fishing fleet in Quy Nhơn. Therefore, this industry is a point of attention for the Ministry of Agriculture and Rural Development. For this industry, it is important to have a decent location with the possibility to extract sea water while being well connected for in and outbound freight.

Phù Cát district
Phù Cát district is the district in which the Đề Gi harbour T-jetty is located. The harbour is one of the focus points for the district due to its economic relevance. The district assigned An Quang as a growing urbanisation, in which more workplaces should be created in the secondary and tertiary sectors. More vessels will simultaneously increase the secondary sector with marine services and transportation, but also the increase in squid will enlarge the squid processing facilities. For the tertiary sector, a goal is set to enlarge the tourist sector. Therefore, the Phù Cát district is highly interested in the enlarging plans of the Đề Gi harbour. For the Phù Cát district, it is important to have sustainable growth of the harbour with labour places for the local community while being a non-tourist deterring development (tỉnh Bình Định 2022a).

Phù Mỹ district
Phù Mỹ district is the district north of the Đề Gi estuary. Two third of the Fresh Water Lagoon is located within the Phù Mỹ district including the new shelter area of the Đề Gi Harbour. The Phù Mỹ district is focusing on the growth of the tourism industry while keeping the current economic activities. The growth of the Đề Gi port is an opportunity for the workforce of the Phù Mỹ district. For both tourist, harbour and economic developments a new transportation network is realised, which can be seen as a commitment by the Phù Mỹ district to these three subjects. Therefore, the Phù Mỹ district is eager to facilitate the port enlargement while keeping the tourist developments satisfied (tỉnh Bình Định 2022b).

Port authority
The port authority is officially responsible for the activities in the port and therefore also regarding the harbour in Đề Gi. Therefore, this stakeholder has an interest in a well-functioning of the whole system around the Đề Gi area, since almost all activities within the system have an influence on the harbour, which can complicate the activities when it doesn't go smoothly. Therefore, their interest lies quite high and they are able to pursue a high level of power due to it's position as a local authority.

Quy Nhơn Fishermen
Quy Nhơn fishermen have the same characteristics as general fishermen with the special notation that they originate from the port of Quy Nhơn. According to the plans described in chapter 2, these fishermen have to move their home location from Quy Nhơn to Đề Gi, which means that the planned Đề Gi upgrade project has a large influence on them. Their interest is also a safe and well-functioning port and storm shelter, preferably close to their home.

Residents harbour area
This stakeholder comprises the group of people living close to the port. It's expected they have a dependency on the functioning of the port since their main source of income is most likely somewhat

related to the port activities or to support of people working in the port area. Observations show that the An Quang and Vĩnh Lợi residential areas are also culturally connected to the port with an annual fishing festival as an example. Changes in the port prosperity impact the residents of the harbour socially and financially.

Road users
The current transport system is used by many other road users. Those road users will share similar desires with trucks and two or three-wheeled vehicles: a functional traffic network without interruptions or delays. They may become happy with new roads as a result of the harbour but also may oppose when existing roads become congested due to more traffic flow.

Road side residence
Along the roads modelled in the traffic network, many people take residence. Those residents may not like to have more trucks through the streets as a result of an increase in the tonnage of Đề Gi harbour. This group is not very vocal because most are already used to trucks in the streets.

Tourist businesses
Within the area multiple tourist businesses are present. In the future, this amount will increase. Most are and will be located along the coastline. District development plans are based on enlarging this sector for economic growth. Therefore, future tourist resorts can become vocal. For tourist businesses it is important to have a good connection and the surroundings should stay likeable for tourists.

Truck drivers
Long(er) distance transportation is done by trucks. For truckers, it is important to have a location to wait in the harbour compound and to have easy access to the transportation network from the harbour without interruptions or delays. Truckers do have little influence, but when being contracted to fish processing industries this group may have a bigger impact via fish processing industries.

Two or three wheeled good transporting vehicles
Caught fish transportation over short distances is done by two or three-wheeled vehicles. These vehicles can access routes that trucks cannot. Furthermore, they can economically and feasibly supply small quantities of fish to local markets. Therefore, this group has a unique position within the transportation of goods. This group wants to have good road quality but does not necessarily wish for road widening to keep the unique possibilities currently possessed. Enlarging the total fish catch is not very important, only the amount supplied to local markets is important for this group.

C Interview of Locals

During the field trip, multiple interviews have been conducted. This appendix gives an overview of the questions asked.

ĐỀ GI QUESTIONS • GENERAL

What is your job description?

How long are you doing this work?

Can you tell us about the harbour?

Are there any problems in the harbour?

Are there any boats that cannot access the harbour due to the new bridge?

ĐỀ GI QUESTIONS • FISHERMAN

After arriving, what do you do? Do you unload first or something else?

- Unloading the fish
- Rest
- Eating
- Other,..

Where do the goods go?

Who buys the fish from you?

Do you struggle with accessing the harbour due to the new bridge?

How long do you go fishing each time?

When returning to the harbour, is it busy? Do you have to wait to dock? If yes, how long?

When returning to the harbour, within what timeframe do you leave again?

What do you do when a storm is predicted to be present? Specify the timeframe of returning

When a storm is approaching, do you experience congestion in the access channel? If yes, can you describe your experiences?

What stands out in others behaviour when a storm is approaching?

ĐỀ GI QUESTIONS • SALESMAN

From whom do you buy the fish that you are selling?

To whom do you sell the fish?

Do you have to pay fees in order to sell?

ĐỀ GI QUESTIONS • OTHER OCCUPATION

Can you describe what you do in detail?

Are the tasks the same every day?

Do you have a specific routine in these tasks?

D Field Observations

In this appendix, all field observation reports are bundled. First, the road section observation of the network capacity will be described. Later the observation location for the hydraulic part of the research is described.

D.1 Traffic and transportation

D.1.1 Road section observations

The road network has been split up into sections between nodes. During the field observation, all road sections in the study area have been visited, photographed and measured. The locations of the visited road sections are shown in figure 45, the corresponding observations are shown in figure 46 and figure 47.

Figure 45: Road section observation locations

(a) Location 1
(b) Location 2
(c) Location 3
(d) Location 4
(e) Location 5
(f) Location 6
(g) Location 7
(h) Location 8

Figure 46: Road sections observation part 1.

(a) Location 9

(b) Location 10

(c) Location 11

(d) Location 12

(e) Location 13

(f) Location 14

(g) Location 15

(h) Location 16

Figure 47: Road sections observation part 2.

Based on the above observations (pictures), the analysis of every section is described in the text below. This data has been used to determine the capacity of each road section.

D.1.1.1 National highway (QL)

QL1A

This road is the backbone of the national Vietnamese road network. Trucks originating or departing from the Đề Gi harbour with its origin/destination outside the Bình Định province are using this specific road. It is a dual carriageway with mostly two times two lanes plus a motorbike lane but sometimes it is reduced to just two times two lanes. Near and on bridges, the road occasionally turns into a smaller road section of seven metres without markings or separation. The road is quite old and several sections show this characteristic in its quality.

QL19B

This roadway lies outside the designated study area, but southbound trucks departing from DT639 and not bound for the QL1A main road must traverse it. Consequently, it falls under consideration in this section. The average width of the road is 5.8 metres. However, it narrows to five meters in certain segments along the mountain base due to low-hanging trees with sprawling branches. This creates a very challenging road for truck drivers. Furthermore, the presence of numerous shopfronts and residential zones along the route results in occasional setbacks, reducing the effective width by at least one meter. Additionally, there are instances where adequate parking spaces for motorcycles are not readily available, leading to their placement at the road's periphery, further constraining effective road width. In addition to its width, noteworthy physical attributes include street lighting in urbanized sections, intermittent guardrails, and a central dividing line.

D.1.1.2 Provincial roads (DT)

DT632 Chánh Thiện - Chánh Trực

The trail of this road is slightly winding and mainly through rice fields with minimal roadside buildings. Most buildings next to the road have space between the fence and the part where the asphalt starts. Resulting positively in that parked vehicles and pedestrians don't limit the usable width of the road. Leaving the complete 5.8 metres available for traffic. Within the communal area of Chánh Thiện and Chánh Trực, the road has more characteristics of a street with the same mentioned dimensions while being consistent with having a middle line along the entire road.

DT632 Chánh Thiện - Phù Mỹ

The DT632 between Chánh Thiện and Phù Mỹ is a road through an urban area with ribbon development outside the urban area. All property borders are located around one metre from the roadside. This leaves space for pedestrians and the parking of vehicles. Resulting in the full road width being usable. The roadbed is 7.5 metres wide leaving enough space for all vehicle types being able to pass each other. There is street lightning within the ribbon development and urban areas but not along the short stretches without buildings. While the road features a central dividing line, it lacks both lateral demarcation and protective guardrails.

DT633 An Quang - Ngãi An

The entrance to the Đề Gi harbour, located in An Quang and connected to the DT633, serves as the primary road of An Quang, hosting a variety of shops, food courts and restaurants. In several stretches, the street's width of only 5.2 metres poses a challenge for the simultaneous passage of trucks and cars. Furthermore, due to the absence of proper pavement, a considerable portion of space is taken up by pedestrians and motorbikes parked in front of commercial establishments, further restricting usable road space. The road exhibits notable disparities, with certain sections featuring a central demarcation or sidewalks, while the majority lack these features. Additionally, the street encompasses numerous intersecting side roads that may not be easily noticeable, potentially obstructing the visibility of approaching traffic. On the other hand, proceeding from the harbour entrance to the east (DT639), the road has experienced more comprehensive development, boasting a 7.5-metre-wide roadbed, complemented by sidewalks and street lighting.

DT633 Chợ Gồm - Đức Phổ
The DT633, spanning from Chợ Gồm to Đức Phổ, traverses a winding route through a terrain characterized by agricultural plots and residential areas. The road itself measures a mere 5.20 metres in width, with structures and shopfronts situated within close proximity, leaving limited room for diverging. Moreover, owing to its winding nature and the presence of numerous inconspicuous and narrow side streets, the road offers a notably obscured view for road users. Despite regulations prohibiting the passage of trucks weighing 10T or more on this route, such vehicles frequently traverse it to avoid a substantial detour. Notably, the road lacks essential features such as street lighting, guardrails, and delineated sidelines.

DT639 Mỹ Thành – Cát Tiến
This road constitutes a four-lane dual carriageway, featuring two lanes in each direction. It has been recently constructed and is currently in impeccable condition, complete with clear markings, curbing, and illumination. The prescribed speed limit is 80 km/h in non-urban areas and 60 km/h within urban confines. The road exhibits minimal, gently sloping curves. Adjacent to the road, there are select developments thoughtfully positioned to ensure minimal interference with the roadway.

DT640 Đức Phổ - Ngãi An
The DT640, spanning from Đức Phổ to Ngãi An, is a meticulously marked road covering a width of 5.7 metres. Along this stretch, the road winds its way along the edge of a mountain, featuring some elevation changes while maintaining consistently clear visibility of the roadway ahead. To mitigate the drop in elevation on one side of the road, a barrier has been installed. Within this segment, lighting is installed, and buildings line the road at both ends. These structures are situated at a distance of one to ten meters from the road. In the middle section, no supplementary space for diversion exists, as a barrier is present on one side and a drainage ditch on the opposite side of the road.

DT 640 Đức Phổ - Chánh Thiện
The DT640, extending from Đức Phổ to Chánh Thiện, is a roadway threading through both urban and agricultural regions, including shrimp farms and rice paddies, while intersecting several rivers that drain into the Đề Gi lagoon. It also traverses segments of linear development adjacent to the route. With a width of 5.5 metres, the road is flanked by steep and soft shoulders. Buildings are situated directly adjacent to the road's edge. Notably, the road is marked with a central dividing line, but it lacks guardrails or lighting infrastructure.

DT640 Ngãi An - Tân Thắng
The road, meandering through a mixed urban and forested environment, exhibits some curvature. The roadside is frequently utilized by pedestrians and for parking, consequently reducing available space for traffic. In most instances, trucks are able to pass each other without deviation. However, some specific locations suffer from space constraints, where road activities limit clearance to the extent that even a truck and motorbike may barely pass one another. Despite, permissions for trucks weighing up to 22 tons, certain ambiguous curves are present, requiring truck drivers to cut corners without clear visibility of approaching traffic. Road markings are in place and the presence of curbs and minimal guardrails varies depending on the location. It is noticeable that within the urbanized segment, lighting is present.

D.1.1.3 District roads

This section consists of roads that officially are not classified as a motorway, a national highway, a provincial road or a smaller major road (CT, QL, DT, D). Within this list, only the roads are mentioned which are or may be used for transportation around the Đề Gi area.

Xuân Bình - Vĩnh Lợi

This road is a very narrow street, presenting challenges in accommodating both cars and motorbikes passing each other simultaneously depending on the location. Throughout its length, cars are compelled to manoeuvre with caution to pass one another due to the constrained width. The roadside terrain is predominantly characterized by steep inclines, soft ground or a combination of both features. Despite the limited space, the road permits the passage of heavy trucks weighing up to 22 tons, making it a factor that contributes to its frequent utilization. This road serves as a vital passageway for the transportation of goods from the abundant shrimp farms in the vicinity, alongside its current usage by construction trucks. Along its course, one encounters numerous residential buildings, shrimp farms and in the locality of Vĩnh Lợi, commercial establishments. While some buildings are positioned within a mere metre of the road, a general trend is observed where structures maintain a minimum distance of at least two metres from the road.

Mỹ Thành - Tân Thành

This road, despite not being classified as a provincial road, exhibits notable width and predominantly follows a straight trajectory, featuring one sharp curve. Its construction material consists of concrete plates, with some exhibiting uneven connections, thereby posing potential hazards for motorbike users. The road is subject to an imposed speed limit of 80 km/h. It traverses an embankment through a forested area and lacks any side roads. Notably, no road markings, curbs, or lighting fixtures are in place. It's worth noting that this road serves as a seamless extension of the recently constructed DT639, creating a funnel-like configuration between these two road sections.

Chánh Trực - Tân Thành

This road is a narrow thoroughfare, measuring only 4.1 metres in width. It is constructed on top of an embankment situated amidst rice paddies, leading to steep and unstable shoulders along the sides. Notably, there are dwellings situated alongside the road, each allowing for approximately one metre of level space between the roadbed and their fronts. This area is utilized for vehicles to manoeuvre when they are unable to pass each other directly on the roadbed. This road experiences a substantial volume of freight traffic, as it serves as the sole connecting route between the recently constructed DT639 and the pre-existing DT632, which extends northward. Noteworthy is the absence of a central dividing line, side markings, barriers, or street lighting along the road.

Vĩnh Lợi - Đề Gi bridge

The most direct route between Vĩnh Lợi and the Đề Gi bridge spans a mere 50 metres, comprising a very narrow and steep stone debris path. Only a short segment, approximately 50 metres in length, connects to the DT639. This path sees heavy traffic primarily from motorbikes and trikes commuting between Vĩnh Lợi and An Quang, owing to its directness. The shortest alternative route, while staying on paved roads, extends approximately 16 kilometres. Consequently, this narrow path serves as the primary link for transporting fish from the Đề Gi harbour to Vĩnh Lợi. It is worth noting that this mode of transportation is exclusively facilitated by motorbikes and trikes characterized by elevated wheels, as cargo tuk-tuks or larger vehicles find traversal impossible due to the path's narrow 0.5-metre width and protruding stones.

D.1.1.4 Future situation

In the scope area, there are multiple infrastructural projects under construction or being planned. The most important projects will be described below.

CT01: North south motorway

In response to the nearing of the capacity limits on the QL1A, it is important to expand the infrastructure. Notably, the QL1A exhibits considerable ribbon development, frequently aligning with the north-south railway line. However, the extensive deconstruction required to widen this road from two sets of three lanes to four presents a formidable challenge. As a strategic alternative, plans have been set in motion for the construction of a parallel motorway that will run adjacent to the existing QL1A national highway. This decision offers multifaceted benefits, including the segregation of local and long-distance traffic. This design fosters a more streamlined flow of traffic on the motorway, while the inherent turbulence of local traffic is confined to the rudimentary QL1A which is also strengthened by the proposed refusal of vehicles with less than four wheels or the minimal distance of five kilometres between on and off-ramp with a side road for lower level vehicles Tiêu Chuẩn Việt Nam 2005. The road will initially have two times two lanes and finally two times three lanes with a total wide of 32.25 metres within the scope area Bộ Giao Thông Vận Tải 2022.

DT639 Lạc Sơn - Mỹ Thành (extension DT639 to CT01)

The northern end of the current DT639 dual carriageway, situated in close proximity to Mỹ Thành abruptly converts into a lower-level road as described in the current situation. This shift arises from the implementation of a new alignment for the DT639, while the road presently serves as a coastal provincial route running from north to south, its future role will be to link the primary north-south motorway to an expanse of coastline. It is important to note, however, that this connector will not mirror the dual carriageway configuration of the existing section. The envisioned design entails a road width of 12 meters in each direction. This allocation incorporates a 3.5-meter-wide lane for cars, a 2-meter-wide lane for motorcycles, and a 0.5-meter-wide redirection lane. The provincial road will be equipped with guide rails and lighting.

DT640 Ngãi An(CT633) - An Quang(CT639) (bypass An Quang section CT633)

To the south of the An Quang commune, a new provincial road will be constructed as a dual carriageway. This road will serve as an alternative route, bypassing the An Quang main street section of the CT633. The upcoming road will mirror the design of the recently constructed CT639. It is slated to be 9.25 metres wide in each direction, including a two-meter central guidance strip. This width comfortably accommodates two lanes for vehicles, alongside a dedicated lane for motorcycles. Amenities such as street lighting, clear markings and a curb are included in the design to facilitate speeds of up to 80 km/h.

D.1.2 Observed types of transport vehicles

Around the Đề Gi harbour, multiple vehicles are present. From every category used within this research, an observed vehicle within the scope area is added in figure 48.

(a) Motorbike

(b) Trike

(c) Cargo tuk-tuk

(d) Ice truck

(e) Small truck

(f) Medium truck

(g) Large truck

Figure 48: Transport vehicles as observed in Đề Gi

D.2 Hydraulic observations

To better comprehend the morphodynamics and hydrodynamics of the research field, three field observations were conducted at the Đề Gi area along the coastline (figure 49):

- Location 1: shoreline north from the Đề Gi access channel
- Location 2: shoreline south from the Đề Gi access channel
- Location 3: shoreline right at the south side of the Đề Gi breakwater at the south side of the access channel

Figure 49: Locations field observations

Two small demonstrations are performed in order to better understand the circumstances at these three locations:

- The 'Orange Survey': throwing an orange into the sea will reveal the direction of the along-shore current. Additionally, if the orange's location and passage time are monitored, it is possible to estimate the velocity of the current.
- The Sand Samples: collecting sand samples will help to estimate the mean particle size on the beach, the relative variability of the deposits' locality and to estimate systematic variations in beach properties.

The table below provides a brief description of the morphology, hydrodynamics, ecology and human interventions for each location.

	Location 1	Location 2	Location 3
Time	19 September 2023 around 16.30h	19 September 2023 around 17.10h	20 September 2023, around 9.45h
Morphology	The overall beach slope is 10-15% (figure 50). Some dune erosion can be observed. There are multiple wrack-lines. Figure 50a might indicate the water level rise during storm conditions. Figure 50b shows the wrack line during high tide. There are not really signs of erosion nor accretion. The coastline seems stable. The sediment characteristics at location 1 are shown in figure 53.	The overall beach slope is 10-15% (figure 51). The shoreline consists of inlets and bulges, where accretion and erosion occur. Close to the shoreline, some small weak spots can be observed in the inlet of the beach. These weak spots have a slope of 45%. The sediment characteristics at location 2 are shown in figure 53.	The overall beach slope is 7% (figure 52). There are no real dunes. There are no clear weak spots. Accretion occurs near the breakwater, see figure 52a. Sand samples are taken and shown in figure 53.
Hydrodynamics	Wind conditions: NNE wind with a windspeed of 11 km/h. The offshore waves follow the same direction as the wind, but the incoming waves nearshore tend to refract. The wave height is approximately 0.5 metre. The wave period is approximately 5 seconds. The tidal conditions are shown in figure 54a. The time of the orange survey is 3 minutes and 20 seconds over a distance of 20 metres.	Wind conditions: NNE wind with a windspeed of 11 km/h. The offshore waves follow the same direction as the wind, but the incoming waves nearshore tend to refract. The wave height is approximately 0.3 metre. The wave period is approximately 3.5 seconds. The tidal conditions are shown in figure 54a. The time of the orange survey is 4 minutes and 17 seconds over a distance of 20 metre.	Wind conditions: E wind with a windspeed of 6 km/h. The offshore waves follow the same direction as the wind, but the incoming waves nearshore tend to refract. The wave height is approximately 0.1 metre. The wave period is approximately 3 seconds. The tidal conditions are shown in figure 54b. The time of the orange survey is 7 minutes and 50 seconds over a distance of 20 metre.
Human interventions	None	Water drainage constuction of shrimp farms.	Squid farms and water outlets of the farm. Breakwater.
Ecology	The vegetation is monotonous: dune grass species (marram grass), some sort of ivy species expending on the ground. There is a small pool filled with water. This pool is expected to be human-made. The bushy landscape land inward can be found more hilly, where possibly more elevation levels can be experienced. The forest consists mainly of coniferous species and the sandiness of the dune system continues into the forest as well.	The vegetation is monotonous: ivy species expending on the ground and some coniferous species.	There is no vegetation at the beach, as well as at the breakwater. There is some black fine shiny material washing up the shore (figure 52e). Crabs in different sizes.

Table 18: Observations of three locations at the Đề Gi area along the coastline

(a) North direction

(b) South direction

Figure 50: Observations location 1

(a) North direction

(b) South direction

(c) South direction more inland

Figure 51: Observations location 2

(a) North direction

(b) North direction more inland

(c) South direction

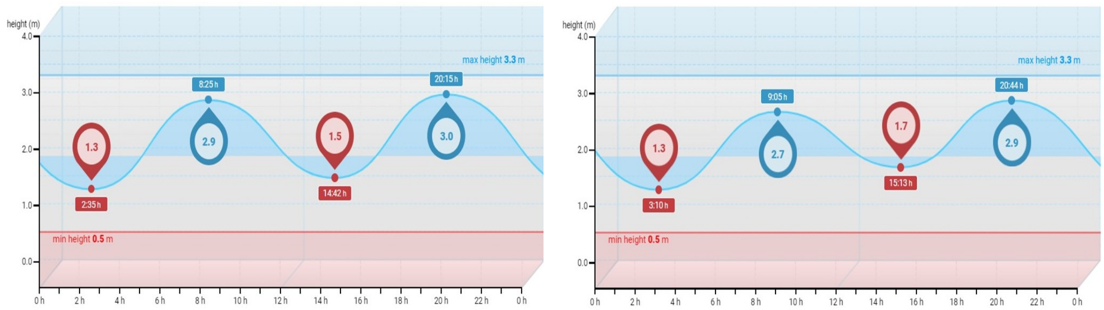
(d) Inland

(e) Sediment

(f) Breakwater

Figure 52: Observations location 3

Figure 53: Sand samples at three different locations in the Đề Gi area.



(a) 19 September 2023

(b) 20 September 2023

Figure 54: Tidal conditions (Tides4fishing n.d.)

E Supporting tables road capacity

To calculate the capacity the Indonesian highway design guideline is used Directorate General of Highways 1993.

This guideline states the capacity for each road section in the network can be calculated with equation 8.

$$C = C_0 \times F_W \times F_{KS} \times F_{SP} \times F_{SF} \tag{8}$$

With:

$$C = Capacity\,of\,the\,section$$
$$C_0 = Base\,capacity$$
$$F_W = Carriageway\,width\,factor$$
$$F_{KS} = Effective\,shoulder\,width\,factor$$
$$F_{SP} = Directional\,split\,factor$$
$$F_{SF} = Side\,friction\,factor$$

All factors used within 8 can be derived from the following tables.

Table 19: Base capacity

Lanes	PCU/h
2	2900
4	5700

Table 20: Carriageway width factor

Lanes	Carriageway width	factor
2	0.5	0.066
2	3.5	0.462
2	4.1	0.5412
2	5.2	0.694
2	5.4	0.728
2	5.5	0.745
2	5.7	0.779
2	5.8	0.796
2	7.5	1.035
2	8	1.07
4	11	0.68
2 × 2	14	1
2 × 2	19	1.11

Table 21: Effective shoulder width factor

Shoulder width	factor
0	0.85
0.5	0.89
1	0.93
1.5	0.96

Table 22: Effective shoulder width factor

Directional split	factor
Median	0.98
No median	1.12

Table 23: Side friction factor

Friction	Example of surroundings	factor
Low	through agricultural area	1
Medium	through mixed agricultural and residential area	0.97
High	through residential area	0.89
Very high	through shopping street	0.86

F Supporting imagery Đề Gi bridge

In this appendix, some supporting imagery is shown for the Đề Gi bridge, including a technical drawing from the KND project (CT Tường Sinh & Viện Đào Tạo và KHUD Miền Trung January 2022) and aerial images.

F.1 Technical drawing

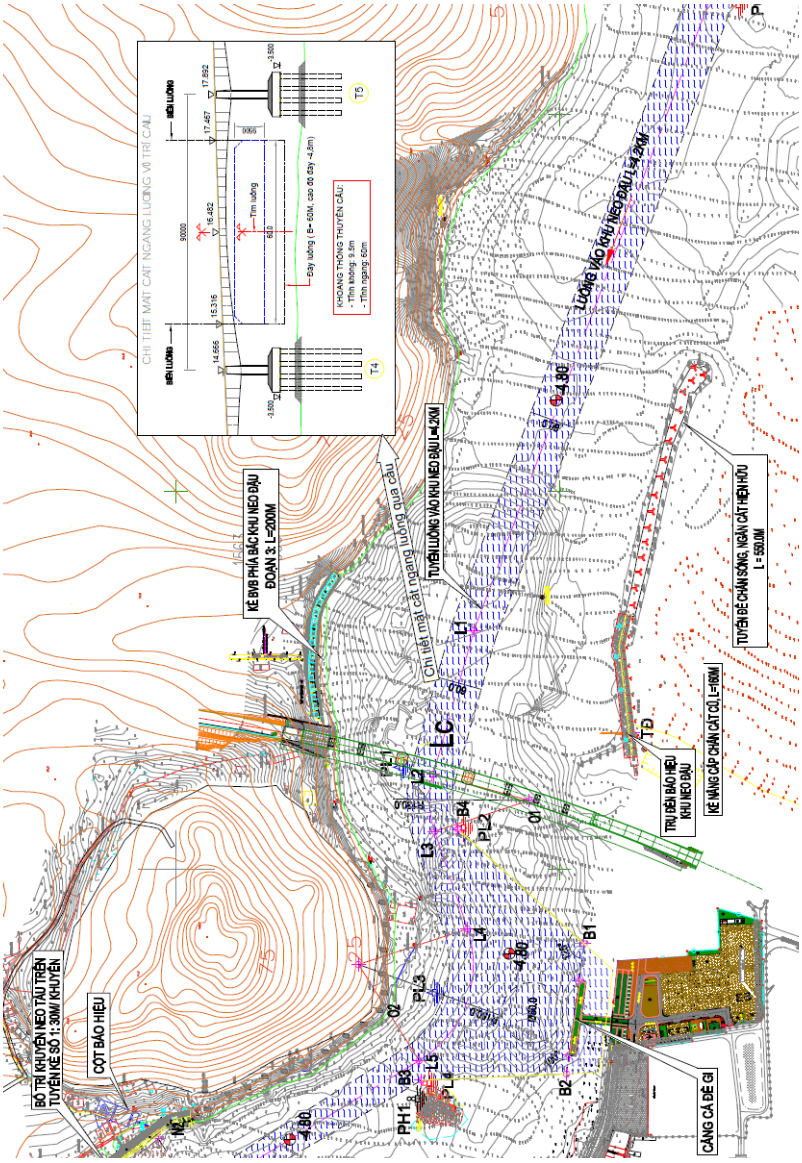


Figure 55: Technical drawing of the access channel including De Gi bridge (the initial proposed 60 m wide access channel is replaced by a 36 m wide channel)

F.2 Aerial photographs

Figure 56: Aerial photograph of access channel and bridge

Figure 57: Aerial photograph of access channel and bridge

G Vessel categorization enlarged

This appendix shows the categorization of the fishing vessels used for the accessibility examination.

Type	Engine power (CV)	Max. draught (m)	Design draught (m)
I	50	1.1	1.65
II	100	1.4	2.1
III	200	1.7	2.55
IV	400	2.4	3.6
V	600	3	4.5

Table 24: Enlarged table of vessel categorization part 1

Type	Current registered number of vessels	%	Future number of vessels daily	%	Future number of vessels in storm shelter	%
I	1300	40	600	85	900	45
II	200	7	70	10	450	22
III	100	3	15	2	450	22
IV	800	25	10	1	100	5
V	800	25	5	1	100	5
Total amount of vessels	3200	100	700	100	2000	100

Table 25: Enlarged table of vessel categorization part 2

H Python notebook UKC channel accessibility

This paragraph includes the full Python notebook used to compute the UKC for the channel accessibility.

UKC channel

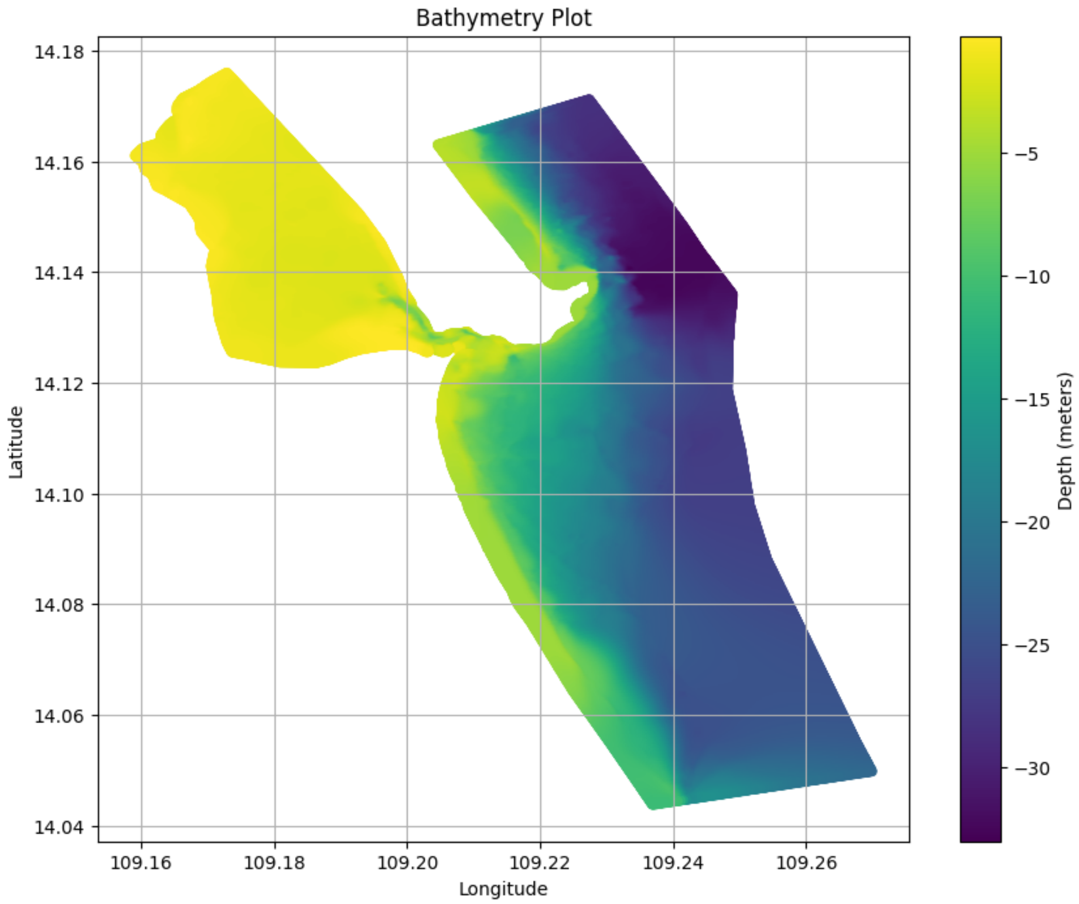
November 2, 2023

[1]:
```
# load in packages
import pandas as pd
import numpy as np
import pyproj
import matplotlib.pyplot as plt
import math
import geopandas as gpd
from matplotlib.pyplot import text
```

[2]:
```
# Define the UTM and WGS84 coordinate systems
utm_zone = 48
utm_northern = True  # Northern hemisphere
utm_epsg = f"EPSG:{32600 + utm_zone}" if utm_northern else f"EPSG:{32700 +␣
↪utm_zone}"
wgs84_epsg = "EPSG:4326"  # WGS84
utm_to_wgs84 = pyproj.Transformer.from_crs(utm_epsg, wgs84_epsg, always_xy=True)
df1 = pd.read_csv("DEGI.txt", delim_whitespace=True)
df1[['Longitude', 'Latitude']] = df1.apply(lambda row: utm_to_wgs84.
↪transform(row['Easting'], row['Northing']), axis=1, result_type='expand')
```

[3]:
```
plt.figure(figsize=(10, 8))
plt.scatter(df1['Longitude'], df1['Latitude'], c=df1['Depth'], cmap='viridis',␣
↪s=20)
plt.colorbar(label='Depth (meters)')
plt.xlabel('Longitude')
plt.ylabel('Latitude')
plt.title('Bathymetry Plot')
plt.grid(True)
plt.show()
```

1



[9]:
```
# load in the coordinates of the sample locations from the centreline of the␣
↪access channel
centre_line = pd.read_csv('New_center_line.txt', delim_whitespace=True)
centre_line
```

[9]:

	type	latitude	longitude	altitude	(m)
0	T	14.124570	109.216517	0.0	NaN
1	T	14.124585	109.216489	0.0	NaN
2	T	14.124593	109.216460	0.0	NaN
3	T	14.124600	109.216431	0.0	NaN
4	T	14.124608	109.216401	0.0	NaN
..	…	…	…	…	…
777	T	14.130669	109.201815	0.8	NaN
778	T	14.130687	109.201806	0.7	NaN
779	T	14.130705	109.201792	0.7	NaN
780	T	14.130724	109.201783	0.6	NaN
781	T	14.130738	109.201771	0.6	NaN

```
[782 rows x 5 columns]
```

[10]:
```python
# convert dataframe to array of coordinates for bathymetry
bathy_coordinates = list(zip(df1['Longitude'], df1['Latitude']))

# convert dataframe to array of coordinates for channel sample points
channel = list(zip(centre_line['longitude'], centre_line['latitude']))

# create variable to store the closest survey coordinates to sample coordinates
sample_points = []

# find closest coordinates
for i in range(len(channel)):
    target = channel[i]
    closest = min(bathy_coordinates, key=lambda point: math.
 ↪hypot(target[1]-point[1], target[0]-point[0]))

    sample_points.append(closest)
```

[11]:
```python
# check if the amount of sample points is similar to the number of coordinates␣
 ↪in the channel
len(sample_points)
```

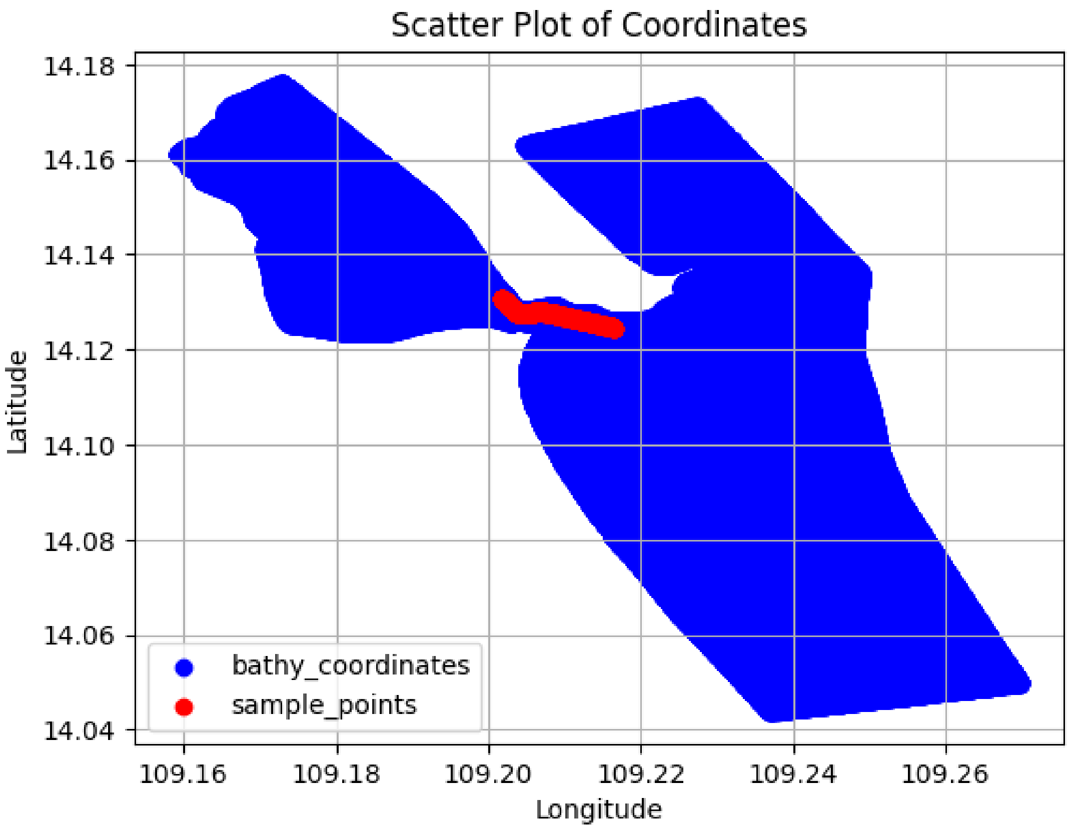
[11]:
```
782
```

[12]:
```python
# check if the format style is correct
sample_points[0:10]
```

[12]:
```
[(109.21648675087418, 14.124585137154702),
 (109.21648675087418, 14.124585137154702),
 (109.21648675087418, 14.124585137154702),
 (109.21639435250587, 14.12458675950102),
 (109.21639435250587, 14.12458675950102),
 (109.21639435250587, 14.12458675950102),
 (109.21630195412588, 14.124588381812034),
 (109.21630361646417, 14.124678554681754),
 (109.21630361646417, 14.124678554681754),
 (109.21621121803632, 14.124680176968232)]
```

[13]:
```python
# visualise sample locations to check if they are correct with the channel␣
 ↪coordinates

# Extract x and y values
x_values, y_values = zip(*bathy_coordinates)
x_sample, y_sample = zip(*sample_points)

# Create a scatter plot
```

```python
plt.scatter(x_values, y_values, c='blue', marker='o', label='bathy_coordinates')
plt.scatter(x_sample, y_sample, c='r', marker='o', label='sample_points')

# Set labels and title
plt.xlabel('Longitude')
plt.ylabel('Latitude')
plt.title('Scatter Plot of Coordinates')

# Show the plot
plt.grid()
plt.legend()
plt.show()
```



[14]:
```python
# create a new dataframe with the sampled coordinates
df2 = pd.DataFrame(sample_points, columns=['Longitude', 'Latitude'])
```

[15]:
```python
# find the index of the bridge
df2[(df2['Latitude'] == x2) & (df2['Longitude'] == x1)]
```

[15]:

```
      Longitude   Latitude
391  109.207028  14.127908
392  109.207028  14.127908
393  109.207028  14.127908
394  109.207028  14.127908
395  109.207028  14.127908
396  109.207028  14.127908
```

[16]:

```
# add the depth at these coordinates from the original bathymatry dataframe
depths = []

for i in range(len(sample_points)):
    x = sample_points[i][0]
    y = sample_points[i][1]
    depths.append(df1[(df1['Latitude'] == y) & (df1['Longitude'] ==␣
 ↪x)]['Depth'].values[0])

df2['depths'] = depths
df2['depths'] = df2['depths'] * -1
```

[17]:

```
df2
```

[17]:

```
      Longitude   Latitude    depths
0    109.216487  14.124585  4.977343
1    109.216487  14.124585  4.977343
2    109.216487  14.124585  4.977343
3    109.216394  14.124587  4.963351
4    109.216394  14.124587  4.963351
..          …          …         …
777  109.201811  14.130706  7.217178
778  109.201811  14.130706  7.217178
779  109.201811  14.130706  7.217178
780  109.201811  14.130706  7.217178
781  109.201811  14.130706  7.217178

[782 rows x 3 columns]
```

[18]:

```
# add a column that computes the deviation from the design depth
design_depth = 4.8

df2['design_depth_dev'] = df2['depths'] - design_depth

df2
```

[18]:

```
      Longitude   Latitude    depths  design_depth_dev
0    109.216487  14.124585  4.977343          0.177343
1    109.216487  14.124585  4.977343          0.177343
```

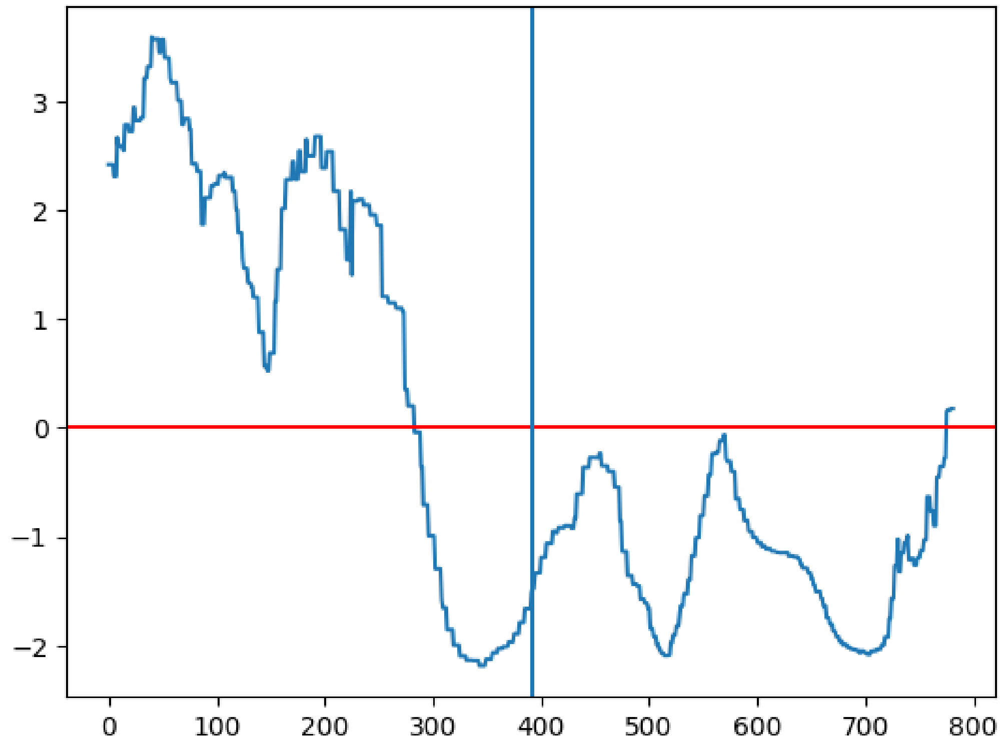
```
2    109.216487  14.124585  4.977343          0.177343
3    109.216394  14.124587  4.963351          0.163351
4    109.216394  14.124587  4.963351          0.163351
..          …          …         …           …
777  109.201811  14.130706  7.217178          2.417178
778  109.201811  14.130706  7.217178          2.417178
779  109.201811  14.130706  7.217178          2.417178
780  109.201811  14.130706  7.217178          2.417178
781  109.201811  14.130706  7.217178          2.417178

[782 rows x 4 columns]
```

[19]:

```
# visualise the deviation from the design depth
plt.plot(df2.index, df2.iloc[::-1]['design_depth_dev'])
plt.axhline(0, color='r', label='bathymetry')

# add a vertical line at location of the bridge
plt.axvline(392)
```

[19]:

```
<matplotlib.lines.Line2D at 0x7f4a2ec53b50>
```



The next step is to reproduce the above steps and create a function with input a scenario (water level or vessel) and output a graph

[20]:
```
# create a function for the coordinate sampler

def sampler():
    centre_line = pd.read_csv('New_center_line.txt', delim_whitespace=True)

    # convert dataframe to array of coordinates for bathymetry
    bathy_coordinates = list(zip(df1['Longitude'], df1['Latitude']))

    # convert dataframe to array of coordinates for channel sample points
    channel = list(zip(centre_line['longitude'], centre_line['latitude']))

    # create variable to store the closest survey coordinates to sample␣
↪coordinates
    sample_points = []

    # find closest coordinates
    for i in range(len(channel)):
        target = channel[i]
        closest = min(bathy_coordinates, key=lambda point: math.
↪hypot(target[1]-point[1], target[0]-point[0]))

        sample_points.append(closest)

    df_sampled = pd.DataFrame(sample_points, columns=['Longitude', 'latitude'])


    # add the depth at these coordinates from the original bathymatry dataframe
    depths = []

    for i in range(len(sample_points)):
        x = sample_points[i][0]
        y = sample_points[i][1]
        depths.append(df1[(df1['Latitude'] == y) & (df1['Longitude'] ==␣
↪x)]['Depth'].values[0])

    df_sampled['depths'] = depths
    df_sampled['depths'] = df_sampled['depths'] * -1

    return df_sampled
```

[21]:
```
df_sampled = sampler()
```

[22]:
```
df_sampled
```

```
[22]:     Longitude   latitude    depths
     0    109.216487  14.124585  4.977343
     1    109.216487  14.124585  4.977343
     2    109.216487  14.124585  4.977343
     3    109.216394  14.124587  4.963351
     4    109.216394  14.124587  4.963351
     ..          …          …         …
     777  109.201811  14.130706  7.217178
     778  109.201811  14.130706  7.217178
     779  109.201811  14.130706  7.217178
     780  109.201811  14.130706  7.217178
     781  109.201811  14.130706  7.217178

     [782 rows x 3 columns]
```

The plan is to create 3 dataframes, for LW, MW and HW. In these dataframes have all deviations from the design water level for eacht vessel type. First is to create a dataframe for LW with the proposed design depth of 4.8 meter.

```
[23]: lw_interval = [0.16, -0.41, -0.95]
keys = ['1%', '50%', '99%']

design_depth = 4.8

df_sampled_LW = df_sampled.copy()

for i in range(len(lw_interval)):
    df_sampled_LW[f'{keys[i]} design depth_dev'] = df_sampled_LW['depths'] -
 ↪design_depth + lw_interval[i]
```

```
[24]: df_sampled_LW
```

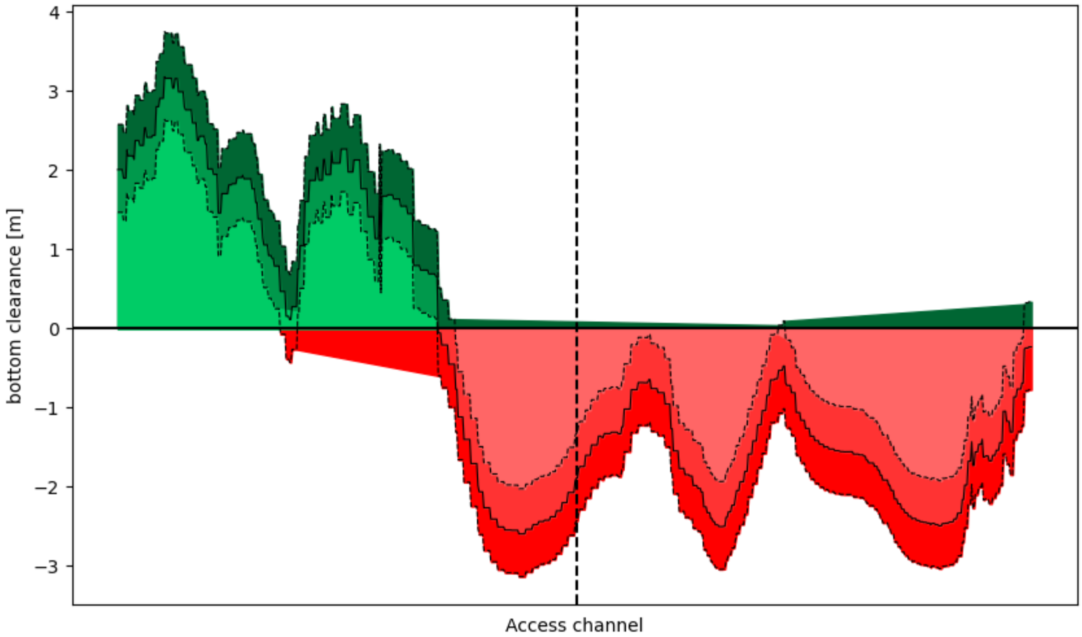
```
[24]:     Longitude   latitude    depths  1% design depth_dev  \
     0    109.216487  14.124585  4.977343             0.337343
     1    109.216487  14.124585  4.977343             0.337343
     2    109.216487  14.124585  4.977343             0.337343
     3    109.216394  14.124587  4.963351             0.323351
     4    109.216394  14.124587  4.963351             0.323351
     ..          …          …         …                    …
     777  109.201811  14.130706  7.217178             2.577178
     778  109.201811  14.130706  7.217178             2.577178
     779  109.201811  14.130706  7.217178             2.577178
     780  109.201811  14.130706  7.217178             2.577178
     781  109.201811  14.130706  7.217178             2.577178

          50% design depth_dev  99% design depth_dev
     0               -0.232657            -0.772657
```

```
1            -0.232657          -0.772657
2            -0.232657          -0.772657
3            -0.246649          -0.786649
4            -0.246649          -0.786649
..                 …                  …
777           2.007178           1.467178
778           2.007178           1.467178
779           2.007178           1.467178
780           2.007178           1.467178
781           2.007178           1.467178

[782 rows x 6 columns]
```

[25]:

```
# plot the dataframe

plt.figure(figsize=(10,6))

plt.axhline(0, color='k')

for i in range(len(lw_interval)):

    locations = df_sampled_LW.index
    values = df_sampled_LW.iloc[::-1][f'{keys[i]} design depth_dev']

    linestyle = ('--', '-', '--')

    c1 = ['#006633', '#00994C', '#00CC66']
    c2 = ['#FF0000', '#FF3333', '#FF6666']

    plt.plot(locations, values, color='k', linewidth=0.8,␣
 ↪linestyle=linestyle[i])

    plt.fill_between(locations[(values > 0)], values[(values > 0)], 0,␣
 ↪color=c1[i])

    keys_inv = ['99%', '50%', '1%']
    values_inv = df_sampled_LW.iloc[::-1][f'{keys_inv[i]} design depth_dev']

    plt.fill_between(locations[(values_inv < 0)], 0, values_inv[(values_inv <␣
 ↪0)], color=c2[i])

plt.axvline(392, color='k', linestyle='--')

plt.xticks([])
plt.xlabel('Access channel')
plt.ylabel('bottom clearance [m]')
```

[25]: Text(0, 0.5, 'bottom clearance [m]')



Next step is to create the dataframes for LW MW and HW for 5 predefined vessel types. All vessel draughts are multiplied by 1.5 to comply with the design requirements

[26]:
```
lw_interval = [0.16, -0.41, -0.95]
mw_interval = [0.84, 0.08, -0.76]
hw_interval = [1.05, 0.53, 0.07]

draughts = [1.65, 2.1, 2.55, 3.6, 4.5]

keys_interval = ['1%', '50%', '99%']
keys_type = ['type I', 'type II', 'type III', 'type IV', 'type V']


df_sampled_LW = df_sampled.copy()
df_sampled_MW = df_sampled.copy()
df_sampled_HW = df_sampled.copy()

# create LW dataframe
for i in range(len(draughts)):
    for j in range(len(lw_interval)):
        df_sampled_LW[f'{keys_type[i]}_{keys_interval[j]}'] = 
 ↪df_sampled_LW['depths'] - draughts[i] + lw_interval[j]

# create MW dataframe
```

```
for i in range(len(draughts)):
    for j in range(len(mw_interval)):
        df_sampled_MW[f'{keys_type[i]}_{keys_interval[j]}'] = 
 ↪df_sampled_MW['depths'] - draughts[i] + mw_interval[j]


# create HW dataframe
for i in range(len(draughts)):
    for j in range(len(hw_interval)):
        df_sampled_HW[f'{keys_type[i]}_{keys_interval[j]}'] = 
 ↪df_sampled_HW['depths'] - draughts[i] + hw_interval[j]
```

[27]:
```
df_sampled_LW
```

[27]:
```
      Longitude   latitude    depths  type I_1%  type I_50%  type I_99%  \
0    109.216487  14.124585  4.977343   3.487343    2.917343    2.377343
1    109.216487  14.124585  4.977343   3.487343    2.917343    2.377343
2    109.216487  14.124585  4.977343   3.487343    2.917343    2.377343
3    109.216394  14.124587  4.963351   3.473351    2.903351    2.363351
4    109.216394  14.124587  4.963351   3.473351    2.903351    2.363351
..          …          …         …          …           …           …
777  109.201811  14.130706  7.217178   5.727178    5.157178    4.617178
778  109.201811  14.130706  7.217178   5.727178    5.157178    4.617178
779  109.201811  14.130706  7.217178   5.727178    5.157178    4.617178
780  109.201811  14.130706  7.217178   5.727178    5.157178    4.617178
781  109.201811  14.130706  7.217178   5.727178    5.157178    4.617178

     type II_1%  type II_50%  type II_99%  type III_1%  type III_50%  \
0      3.037343     2.467343     1.927343     2.587343      2.017343
1      3.037343     2.467343     1.927343     2.587343      2.017343
2      3.037343     2.467343     1.927343     2.587343      2.017343
3      3.023351     2.453351     1.913351     2.573351      2.003351
4      3.023351     2.453351     1.913351     2.573351      2.003351
..          …           …            …            …             …
777    5.277178     4.707178     4.167178     4.827178      4.257178
778    5.277178     4.707178     4.167178     4.827178      4.257178
779    5.277178     4.707178     4.167178     4.827178      4.257178
780    5.277178     4.707178     4.167178     4.827178      4.257178
781    5.277178     4.707178     4.167178     4.827178      4.257178

     type III_99%  type IV_1%  type IV_50%  type IV_99%  type V_1%  \
0        1.477343    1.537343     0.967343     0.427343   0.637343
1        1.477343    1.537343     0.967343     0.427343   0.637343
2        1.477343    1.537343     0.967343     0.427343   0.637343
3        1.463351    1.523351     0.953351     0.413351   0.623351
4        1.463351    1.523351     0.953351     0.413351   0.623351
..            …           …            …            …          …
```

```
777      3.717178    3.777178     3.207178     2.667178   2.877178
778      3.717178    3.777178     3.207178     2.667178   2.877178
779      3.717178    3.777178     3.207178     2.667178   2.877178
780      3.717178    3.777178     3.207178     2.667178   2.877178
781      3.717178    3.777178     3.207178     2.667178   2.877178

     type V_50%  type V_99%
0      0.067343   -0.472657
1      0.067343   -0.472657
2      0.067343   -0.472657
3      0.053351   -0.486649
4      0.053351   -0.486649
..          …          …
777    2.307178    1.767178
778    2.307178    1.767178
779    2.307178    1.767178
780    2.307178    1.767178
781    2.307178    1.767178

[782 rows x 18 columns]
```

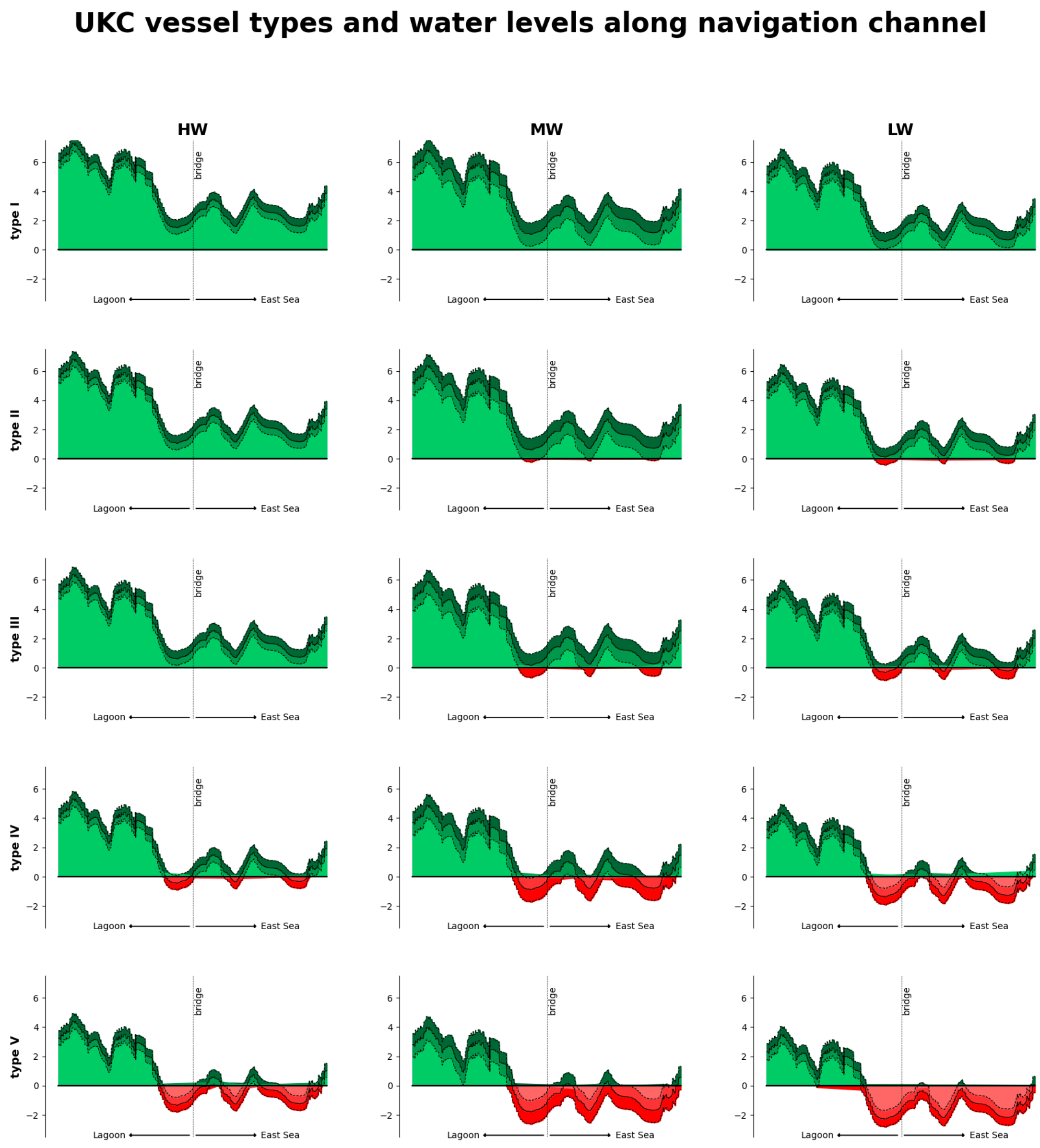
plot all vessels for low water

[28]:
```
# create keys to call dataframes
keys_interval = ['1%', '50%', '99%']
keys_type = ['type I', 'type II', 'type III', 'type IV', 'type V']


# generate subplots
fig, axs = plt.subplots(5, 3, figsize=(20, 20), sharex='col')

plt.subplots_adjust(hspace=0.3)

# Defining custom 'xlim' and 'ylim' values.
custom_ylim = (-3.5, 7.5)

# Setting the values for all axes.
plt.setp(axs, ylim=custom_ylim)

# set column and row names
cols = ['{}'.format(col) for col in ['HW', 'MW', 'LW']]
rows = ['{}'.format(row) for row in keys_type]

for ax, col in zip(axs[0], cols):
    ax.set_title(col, fontsize=18, fontweight='bold')

for ax, row in zip(axs[:,0], rows):
```

```
    ax.set_ylabel(row, rotation=90, fontsize=13, fontweight='bold')


for ax in axs.flat:
    ax.set_xlabel('')  # Set x-label to an empty string
    ax.set_xticks([])

# plot vertical line at the bridge
    ax.axvline(392, color='k', linestyle='--', linewidth=0.5, label='bridge')
    ax.text(395, 5, 'bridge', rotation=90)

# Remove axis except left axis
    ax.spines['left'].set_visible(True)
    ax.spines['top'].set_visible(False)
    ax.spines['right'].set_visible(False)
    ax.spines['bottom'].set_visible(False)

    # draw arrows to indicate direction of channel
    ax.arrow(400, -3.4, 170, 0, color='k', head_length=5, head_width=0.25, ␣
↪length_includes_head=False)
    ax.arrow(382, -3.4, -170, 0, color='k', head_length=5, head_width=0.25,␣
↪length_includes_head=False)
    ax.text(590, -3.6, 'East Sea')
    ax.text(100, -3.6, 'Lagoon')


# plot all vessel types for low water
for i in range(len(draughts)):

    for j in range(len(lw_interval)):

        # get index values of sample locations to use a x ticks
        locations = df_sampled_LW.index

        # get y-values to be plotted for given draught and 3 intervals
        values = df_sampled_LW.iloc[::-1][f'{keys_type[i]}_{keys_interval[j]}']

        # some aesthetics
        linestyle = ('--', '-', '--')
        c1 = ['#006633', '#00994C', '#00CC66']
        c2 = ['#FF0000', '#FF3333', '#FF6666']

        # plot positive confidence interval levels
        axs[i,2].plot(locations, values, color='k', linewidth=0.8,␣
↪linestyle=linestyle[j])

        # fill area under positive confidence interval levels
```

```
        axs[i,2].fill_between(locations[(values > 0)], values[(values > 0)], 0,␣
↪color=c1[j])

        # pull out a trick to inverse colour the negative confidence intervals
        keys_interval_inv = ['99%', '50%', '1%']
        values_inv = df_sampled_LW.iloc[::
↪-1][f'{keys_type[i]}_{keys_interval_inv[j]}']

        axs[i,2].fill_between(locations[(values_inv < 0)], 0,␣
↪values_inv[(values_inv < 0)], color=c2[j])

        # create a horizontal line around 0
        zero = np.zeros(len(locations))
        axs[i,2].plot(locations, zero, 'k')



# plot all vessel types for mean water
for i in range(len(draughts)):

    for j in range(len(mw_interval)):

        locations = df_sampled_MW.index
        values = df_sampled_MW.iloc[::-1][f'{keys_type[i]}_{keys_interval[j]}']

        linestyle = ('--', '-', '--')

        c1 = ['#006633', '#00994C', '#00CC66']
        c2 = ['#FF0000', '#FF3333', '#FF6666']

        axs[i,1].plot(locations, values, color='k', linewidth=0.8,␣
↪linestyle=linestyle[j])

        axs[i,1].fill_between(locations[(values > 0)], values[(values > 0)], 0,␣
↪color=c1[j])

        keys_interval_inv = ['99%', '50%', '1%']
        values_inv = df_sampled_MW.iloc[::
↪-1][f'{keys_type[i]}_{keys_interval_inv[j]}']

        axs[i,1].fill_between(locations[(values_inv < 0)], 0,␣
↪values_inv[(values_inv < 0)], color=c2[j])

        zero = np.zeros(len(locations))
        axs[i,1].plot(locations, zero, 'k')
```

```
        plt.xticks([])


# plot all vessel types for high water
for i in range(len(draughts)):

    for j in range(len(hw_interval)):

        locations = df_sampled_HW.index
        values = df_sampled_HW.iloc[::-1][f'{keys_type[i]}_{keys_interval[j]}']

        linestyle = ('--', '-', '--')

        c1 = ['#006633', '#00994C', '#00CC66']
        c2 = ['#FF0000', '#FF3333', '#FF6666']

        axs[i,0].plot(locations, values, color='k', linewidth=0.8,␣
 ↪linestyle=linestyle[j])

        axs[i,0].fill_between(locations[(values > 0)], values[(values > 0)], 0,␣
 ↪color=c1[j])

        keys_interval_inv = ['99%', '50%', '1%']
        values_inv = df_sampled_HW.iloc[::
 ↪-1][f'{keys_type[i]}_{keys_interval_inv[j]}']

        axs[i,0].fill_between(locations[(values_inv < 0)], 0,␣
 ↪values_inv[(values_inv < 0)], color=c2[j])

        zero = np.zeros(len(locations))
        axs[i,0].plot(locations, zero, 'k')


plt.suptitle('UKC vessel types and water levels along navigation channel',␣
 ↪fontsize=30, fontweight='bold')

plt.show()
```


UKC vessel types and water levels along navigation channel
HW
MW
LW
type I
type II
type III
type IV
type V
bridge
Lagoon
East Sea
6
4
2
0
−2

I Python notebook UKC spatial accessibility

This paragraph includes the full Python notebook used to compute the UKC for the spatial accessibility.

spatial

November 2, 2023

Loading packages

[1]:
```
import pandas as pd
import numpy as np
import pyproj
import matplotlib.pyplot as plt
import math
import geopandas as gpd
import matplotlib.ticker as mticker
from matplotlib.colors import LinearSegmentedColormap
```

Convert and add WGS84 to UTM coordinate system to DataFrame

[2]:
```
# Define the UTM and WGS84 coordinate systems
utm_zone = 48
utm_northern = True  # Northern hemisphere
utm_epsg = f"EPSG:{32600 + utm_zone}" if utm_northern else f"EPSG:{32700 +␣
↪utm_zone}"
wgs84_epsg = "EPSG:4326"  # WGS84
utm_to_wgs84 = pyproj.Transformer.from_crs(utm_epsg, wgs84_epsg, always_xy=True)
df1 = pd.read_csv("DEGI.txt", delim_whitespace=True)
df1[['Longitude', 'Latitude']] = df1.apply(lambda row: utm_to_wgs84.
↪transform(row['Easting'], row['Northing']), axis=1, result_type='expand')
df1['Depth'] = df1['Depth'] * -1
```

Creating different dataframes for MLW, MSL and MHW, and add the draft per vessel with respect to the bathymetry survey of 2021

[3]:
```
# creating different dataframes for MLW, MSL and, MHW
df1_MHW = df1[['Longitude','Latitude','Depth']]
df1_MSL = df1[['Longitude','Latitude','Depth']]
df1_MLW = df1[['Longitude','Latitude','Depth']]

# waterlevels wrt Chart Datum
Waterlevel_MHW = 0.53
Waterlevel_MSL = 0.08
Waterlevel_MLW = -0.41
```

1

```python
# draft vesseltypes
type1 = 1.1
type2 = 1.4
type3 = 1.7
type4 = 2.4
type5 = 3.0

# creating lists for MHW per vesseltype
type1_depth_MHW = []
type2_depth_MHW = []
type3_depth_MHW = []
type4_depth_MHW = []
type5_depth_MHW = []

# creating lists for MSL per vesseltype
type1_depth_MSL = []
type2_depth_MSL = []
type3_depth_MSL = []
type4_depth_MSL = []
type5_depth_MSL = []

# creating lists for MLW per vesseltype
type1_depth_MLW = []
type2_depth_MLW = []
type3_depth_MLW = []
type4_depth_MLW = []
type5_depth_MLW = []

# filling lists MHW
for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type1 + Waterlevel_MHW
    type1_depth_MHW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type2 + Waterlevel_MHW
    type2_depth_MHW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type3 + Waterlevel_MHW
    type3_depth_MHW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type4 + Waterlevel_MHW
    type4_depth_MHW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type5 + Waterlevel_MHW
```

```python
    type5_depth_MHW.append(resting_depth)

# filling lists MSL
for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type1 + Waterlevel_MSL
    type1_depth_MSL.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type2 + Waterlevel_MSL
    type2_depth_MSL.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type3 + Waterlevel_MSL
    type3_depth_MSL.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type4 + Waterlevel_MSL
    type4_depth_MSL.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type5 + Waterlevel_MSL
    type5_depth_MSL.append(resting_depth)

# filling lists MLW
for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type1 + Waterlevel_MLW
    type1_depth_MLW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type2 + Waterlevel_MLW
    type2_depth_MLW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type3 + Waterlevel_MLW
    type3_depth_MLW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type4 + Waterlevel_MLW
    type4_depth_MLW.append(resting_depth)

for i in range(len(df1['Depth'])):
    resting_depth = df1['Depth'][i] - type5 + Waterlevel_MLW
    type5_depth_MLW.append(resting_depth)

# adding lists to water level dataframe for MHW
df1_MHW['Type 1'] = type1_depth_MHW
df1_MHW['Type 2'] = type2_depth_MHW
```

```
df1_MHW['Type 3'] = type3_depth_MHW
df1_MHW['Type 4'] = type4_depth_MHW
df1_MHW['Type 5'] = type5_depth_MHW

# adding lists to water level dataframe for MSL
df1_MSL['Type 1'] = type1_depth_MSL
df1_MSL['Type 2'] = type2_depth_MSL
df1_MSL['Type 3'] = type3_depth_MSL
df1_MSL['Type 4'] = type4_depth_MSL
df1_MSL['Type 5'] = type5_depth_MSL

# adding lists to water level dataframe for MLW
df1_MLW['Type 1'] = type1_depth_MLW
df1_MLW['Type 2'] = type2_depth_MLW
df1_MLW['Type 3'] = type3_depth_MLW
df1_MLW['Type 4'] = type4_depth_MLW
df1_MLW['Type 5'] = type5_depth_MLW
```

```
/tmp/ipykernel_220/3756236491.py:104: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
  df1_MHW['Type 1'] = type1_depth_MHW
/tmp/ipykernel_220/3756236491.py:111: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
  df1_MSL['Type 1'] = type1_depth_MSL
/tmp/ipykernel_220/3756236491.py:118: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-
docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy
  df1_MLW['Type 1'] = type1_depth_MLW
```

Define the thresholds for vesseltype draft

[4]:
```
# Define the thresholds for vesseltype draft

lower_threshold = 0.0
upper_threshold_type1 = 0.55
upper_threshold_type2 = 0.7
upper_threshold_type3 = 0.85
```

```
upper_threshold_type4 = 1.0
upper_threshold_type5 = 1.5
```

Define zooming code for focus on the channel

[5]:
```
# Define zooming code for focus on the channel

min_lat, max_lat = 14.124, 14.132
min_lon, max_lon = 109.2015, 109.2175

zoomedMHW = df1_MHW[(df1_MHW['Latitude'] >= min_lat) & (df1_MHW['Latitude'] <=␣
↪max_lat) &
               (df1_MHW['Longitude'] >= min_lon) & (df1_MHW['Longitude'] <=␣
↪max_lon)]

zoomedMSL = df1_MSL[(df1_MSL['Latitude'] >= min_lat) & (df1_MSL['Latitude'] <=␣
↪max_lat) &
               (df1_MSL['Longitude'] >= min_lon) & (df1_MSL['Longitude'] <=␣
↪max_lon)]

zoomedMLW = df1_MLW[(df1_MLW['Latitude'] >= min_lat) & (df1_MLW['Latitude'] <=␣
↪max_lat) &
               (df1_MLW['Longitude'] >= min_lon) & (df1_MLW['Longitude'] <=␣
↪max_lon)]
```

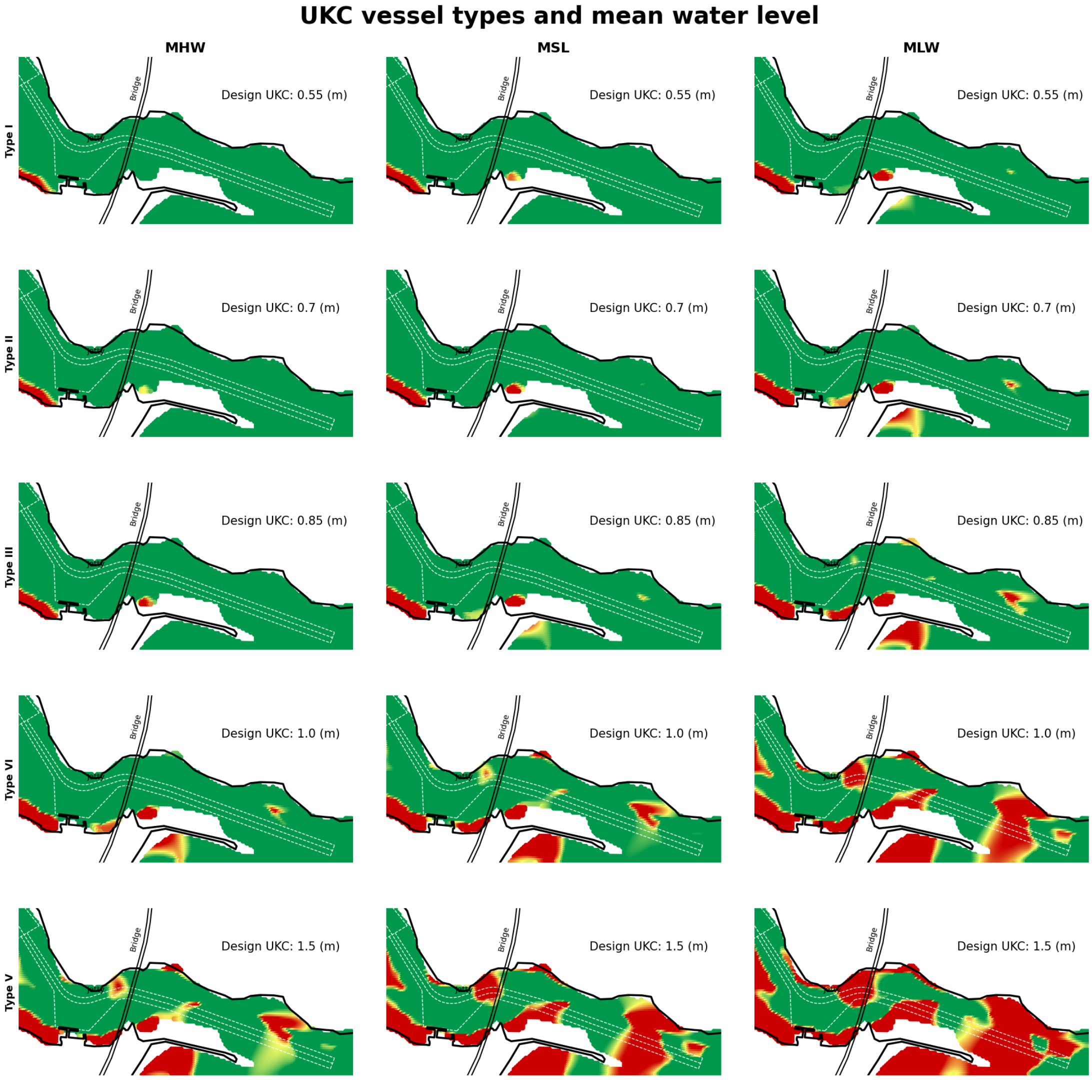
Load plot contour objects

[6]:
```
# Load the CSV file layout channel
csv_file_channel = 'layout_channel_2.csv'
gdf_channel = gpd.read_file(csv_file_channel, GEOM_POSSIBLE_NAMES="WKT")
gdf_channel = gdf_channel[gdf_channel['description'] == 'qhtt']

# Load the CSV file layout map
csv_file_map = 'DuongboDegi.csv'
gdf_map = gpd.read_file(csv_file_map, GEOM_POSSIBLE_NAMES="WKT")

# Load the CSV file layout bridge
csv_file_bridge = 'Bridge De Gi.csv'
gdf_bridge = gpd.read_file(csv_file_bridge, GEOM_POSSIBLE_NAMES="WKT")

def format_coord(x, pos):
    return f'{x:.3f}'
```

[18]:
```
zoomed_dataframes = {
    'MHW': zoomedMHW,
    'MSL': zoomedMSL,
    'MLW': zoomedMLW
```

```
}

level_list = ['MHW', 'MSL', 'MLW']
type_list = ['Type 1', 'Type 2', 'Type 3', 'Type 4', 'Type 5']

keelmargin = [0.55, 0.7, 0.85, 1.0, 1.5]

fig, axes = plt.subplots(5, 3, figsize=(20, 20))

plt.subplots_adjust(hspace=0.3)

# set column and row names
cols = ['{}'.format(col) for col in ['MHW', 'MSL', 'MLW']]
rows = ['{}'.format(row) for row in ['Type I', 'Type II', 'Type III', 'Type VI', 'Type V']]

for ax, col in zip(axes[0], cols):
    ax.set_title(col, fontsize=18, fontweight='bold')

for ax, row in zip(axes[:,0], rows):
    ax.set_ylabel(row, rotation=90, fontsize=13, fontweight='bold')

# plot
for row, water_level in enumerate(level_list):
    for col, type_name in enumerate(type_list):

        zoom = zoomed_dataframes[water_level]

        ax = axes[col, row]  # Get the current axis for this subplot

        # plot contours
        gdf_channel.plot(ax=ax, color='white', label='Channel contour', linestyle='dashed', linewidth=1.0)
        gdf_map.plot(ax=ax, color='Black', label='Map contour', linewidth=2.5)
        gdf_bridge.plot(ax=ax, color='Black', label='Bridge contour', linewidth=1.5, linestyle='-')

        # plot keel vesseltype at certain water level
        cmap = LinearSegmentedColormap.from_list('custom_cmap', [(0, '#CC0000'), (0.5, '#FFFF66'), (1, '#00994c')])
        sc = ax.scatter(zoom['Longitude'], zoom['Latitude'], c=zoom[f'{type_name}'], cmap=cmap, vmin=lower_threshold, vmax=upper_threshold_type1, s=30)
        sc.set_clim(lower_threshold, upper_threshold_type1)

        # formatting plot
```

```
        titletext = f'Keel vesseltype {type_name} at {water_level}'  # Use␣
↪'water_level' instead of 'level_list'
        #ax.set_title(titletext, fontsize=17, fontweight='bold', pad=20)  # Set␣
↪the title on this axis
        ax.set_xlim(min_lon, max_lon)
        # if type_name == 'Type 1':
        #     ax.set_xlabel(f'{water_level}', labelpad=10, fontsize=18,␣
↪fontweight='bold', color='black')
        #     ax.xaxis.set_label_coords(0.5, 1.05)
        ax.set_ylim(min_lat, max_lat)
        # if water_level == 'MHW': ax.set_ylabel(f'{type_name}', fontsize=18,␣
↪fontweight='bold', color='black')
        ax.text(109.2112, 14.13, f'Design UKC: {keelmargin[col]} (m)',␣
↪fontsize=15, color='black')
        ax.text(109.2068, 14.13, f'Bridge', rotation=77, fontsize=10,␣
↪color='black')
        ax.text(109.2048, 14.128, f'Jetty', fontsize=10, color='black')

        # formatting settings
        ax.spines['top'].set_visible(False)
        ax.spines['right'].set_visible(False)
        ax.spines['left'].set_visible(False)
        ax.spines['bottom'].set_visible(False)
        ax.xaxis.set_major_formatter(mticker.FuncFormatter(format_coord))
        ax.yaxis.set_major_formatter(mticker.FuncFormatter(format_coord))
        ax.tick_params(axis='both', which='both', direction='in', top=True,␣
↪right=True)
        ax.set_xticks([])  # Use set_xticks to remove ticks
        ax.set_yticks([])  # Use set_yticks to remove ticks

plt.suptitle('UKC vessel types and mean water level', fontsize=30,␣
↪fontweight='bold')
plt.tight_layout()
plt.savefig(f'UKC vessel types and mean water level.jpg', dpi=300)
plt.show()
```



UKC vessel types and mean water level
MHW
MSL
MLW
Type I
Type II
Type III
Type VI
Type V
Bridge
Design UKC: 0.55 (m)
Design UKC: 0.7 (m)
Design UKC: 0.85 (m)
Design UKC: 1.0 (m)
Design UKC: 1.5 (m)