# Costs Paid in Sand:
# Assessing Land Reclamation and Sand Mining in Western Malaysia

By

Samuel Massey

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of B.A. Honours Geography

Department of Geography
McGill University
Montréal, Québec, Canada
April 2024

**ACKNOWLEDGEMENTS:**

I would first like to thank my honors supervisor, Dr. Mette Bendixen for providing continual feedback, structured lab meetings, and necessary input. Without her extensive knowledge and passion for the topic, this thesis would not have been the same. I would also like to thank my reader and fieldwork supervisor, Dr. Sarah Moser. Without her field course or knowledge of Malay, the findings of this thesis would have no context, and the findings would not have been as rich as they are. I also want to thank her for her input along the way. I would also like to thank Clémence Renault for helping with field observations while on the ground in Malaysia.

Secondly, I would like to thank my fellow members of the Bendixen Lab, Nicolas Dos Santos, Nakiya Noorbhai, and Madelyn West for the input in collective meetings which helped to shape this thesis, as well as advice for research design and tools necessary to the completion of my work.

I would also like to thank my parents for pushing me throughout my life to achieve more than I thought I was capable of. I would also like to thank my friends in the GIC and across McGill for their less structured, but nonetheless necessary support.

Finally, I would like to thank the locals in Malaysia who helped enrich my thesis, even though I cannot name them, as their input was invaluable and provided insight into the Muda sand mining industry.

## TABLE OF CONTENTS

## LIST OF MAPS



## LIST OF FIGURES

**ABSTRACT**

This thesis investigates the often overlooked but extensive impact of sand mining and land reclamation on Malaysia, both environmentally and from a social perspective. For sand mining the focus area is the Muda River, and for land reclamation three key development areas: Forest City, Melaka Gateway, and Penang Island. Through detailed fieldwork and remote sensing analysis, the study reveals an upriver trend in sand mining caused by an unsustainable rate of sand extraction, leading to ecological degradation. Sand mining, driven by urbanization demands, reshapes river morphology, exacerbates erosion, and disrupts sediment flow. Meanwhile, land reclamation projects exhibit speculative urbanism, with significant environmental and economic consequences. The research underscores the interconnection between sand mining and speculative development, emphasizing the exploitation of resources for short-term gains. By highlighting these processes, the study calls for increased vigilance and further research into the connection between these very impactful interdependent processes.



Key Words: Sand mining, Land reclamation, Environmental degradation, Malaysia, Speculative urbanism, Muda River


# CHAPTER 1: INTRODUCTION

Sand is the most mined material on planet Earth (*UNEP*, 2019). It is used for everything from glass making to concrete fabrication to land reclamation, the process of making buildable land for development. These diverse uses contribute to the world's insatiable demand for this seemingly mundane substance (Bendixen et al., 2019). According to the United Nations, there is a global shortage of sand, in part due to rapid development in the Middle East, China, and Southeast Asia (Pascale, 2014). Sand mining also degrades the environment in the locations where it is extracted, dredged, and quarried (Padmalal & Maya, 2014). The literature has already explored many angles of the environmental problems associated with sand mining, but less attention has been paid to the human angle of sand mining. People are inherently impacted by the extraction of resources where they live but due to the relatively small-scale nature of sand mining around the world, impacts are harder to notice compared to larger-scale extractive industries. Sand mining is inherently linked to development and urbanization, and as Southeast Asia continues to develop at a rapid pace in terms of Gross Domestic Product (GDP), the demand for sand has also increased (Lamb et al., 2019). The demand for sand in Malaysia, the country I will be surveying for this thesis, is also greatly impacted by land reclamation. Though sand is mined in both interior Malaysia and offshore, I seek to tie connections between these two sources and tell a unified human story of sand consumption and development in the country.

Furthermore, I chose Malaysia due to its unique position as a cultural bridge between Asia and the Middle East. As a Muslim-majority state, Islam informs many governmental decisions and plays an important role in most people's daily lives. Both from the literature analysis and field experience, I learned quickly that Malaysia is a multiethnic society (Bunnell, 2004; Connolly, 2023). As a product of the British Empire, Malaysia is one of the most culturally diverse nations in the region. Still, the country continues to prosper into the present day with relatively little ethnic tension. Drawing on both Chinese and Middle Eastern influences, the state is keen to develop rapidly and embrace symbols of Western prosperity, even if these are mere abstractions. This desire for an elevated living standard manifests itself in large flashy projects, as if the buildings themselves are modernizing the country (Bunnell, 2004). These new projects are being undertaken by both firms foreign and domestic and are aimed at both markets as prospective buyers respectively. The new demand for the building created greater demand for construction sand and as projects have gotten more ambitious over time, the sea has been seen as the new frontier for development, leading to another boom in sand movement, for land reclamation. In this thesis, I seek to find the inherent links between this new wave of urbanization, fueled by speculation in real estate manifesting as a consequence, both at the locations of development and those externalized, using sand as the lens of analysis. By using sand as a lens of analysis, researchers can track an often overlooked story of one of the most important components of our modern world.

### 1.1 Research Questions

To reach the above aims, I seek to answer the following questions concerning the wave of development in certain regions along the west coast of peninsular Malaysia, specifically in Penang, Melaka, and Forest City.

**Research Question 1:** How are land reclamation and urban development reshaping the modern morphology of coastlines in Western Malaysia, and to what extent has this changed since 1985?

**Research Question 2:** How has the demand for sand at the coasts been externalized to the surrounding hinterland in the past 15 years?

**Research Question 3:** Given the speculative nature of real estate developments in Malaysia, is sand also being mined speculatively?

### 1.2 Structure of the Thesis

In Chapter 2 ‘Literature Review,’ I introduce three themes of literature relevant to my thesis and use relevant examples to frame my research topic. Chapter 3 ‘Context’ details relevant background concerning the history and geographical setting of my research. In Chapter 4, ‘Methodology’ I explain how I collected data both in the field and using remote sensing and GIS. Chapter 5 ‘Results and Analysis’ breaks down my findings both from the field and those found using GIS and remote sensing technology. In Chapter 6, ‘Discussion and Conclusion’ I discuss other themes I noticed while in the field and that I found in my research, how these findings relate to relevant literature and broader trends, as well as points for further research. Finally, I conclude by wrapping up my thesis and summarizing my original questions and findings.

# CHAPTER 2: LITERATURE REVIEW

In this chapter, I identify, explore, and draw comparisons between four main bodies of literature, all intrinsically related to Malaysia's rapid urbanization and sand consumption trends. Firstly, I provide an overview of sand mining and why it is done and examine the canon of environmental sand mining research, to provide a background on the widespread degradation caused by sand's removal from an area. Secondly, I present human-focused sand mining articles, detailing how the sand market functions, the actors present, and the externalities imposed on local people. Thirdly, I present literature on land reclamation, its negative environmental impacts, and why it is done. Lastly, I tie together the previous three bodies of literature with critical urban geography, more specifically with speculative urbanism theory.

## 2.1 Global Sand Mining

Sand is the most mined material on Earth. Sand is mined for many uses, but chiefly for construction and land reclamation, the process of artificially creating new land on swampland or open water (Bendixen et al., 2019; Peduzzi, 2014). Desert sand is less suitable due to its round grain shapes and very fine size, and river sands, or those of glacial origin must normally be used (Al-Harthy et al., 2007). Sand is not extracted the same way everywhere in the world. In high-income countries, like Canada, it is quarried with heavy equipment and small teams of people similar to much any other aggregate would, with varying regimes to enforce that environmental standards are complied with (Mark, 2021). Since independence, many countries in the global south have experienced rapid economic growth. Measured by gross domestic product (GDP), growth has averaged nearly 4% in real terms for Southeast Asia over the past two decades, except for two recessions in 1998 and 2020 (Bendixen et al., 2019; Peduzzi, 2014; *IMF Datamapper: Real GDP Growth*, 2023). This growth has increased demand for sand, as a key ingredient for construction, specifically concrete, and has greatly outpaced supply. As examined in one study, construction demand for sand increased by 45% globally and 300% in the Global South (Zhong et al., 2022). This has caused a rush for sand, which is often filled by exploiting poorer nations with loose environmental laws, like Cambodia and Vietnam, or just illegally mining sand, which can entail breaking environmental laws, small-scale extraction without permits, or in extreme cases, large scale unpermitted extraction (Padmalal & Maya, 2014). This process is quite common around the world, especially in South Asia and Sub-Saharan Africa (Bendixen et al., 2019; Hackney et al., 2021; Lamb et al., 2019). This scarcity has brought UN and broad academic attention to a topic that was mostly overlooked around 2017 (Torres et al., 2017). Since the turn of the century, a plethora of research has been published on the various impacts that sand mining causes on the regions in which it occurs.

In Sub-Saharan Africa, Latin America, and South Asia, artisanal mining undertaken by individuals is the most common (Padmalal & Maya, 2014). Artisanal mining is much harder to control, as it is performed by individuals rather than firms (Mutemeri et al., 2016). This lack of regulation still causes environmental impact, especially when many workers are extracting from the same river, though in some cases it also allows actors to have more agency over the work they perform (Bendixen et al., 2023). This smaller-scale mining, though harder to track, can cause less impact on the environment when compared to large-scale mining (Bendixen et al., 2023). Gavriletea argues that in between these two extremes, we find Southeast Asia, where sand mining is regulated somewhat, but the country's growth demands, more sand to be consumed (2017). Gavriletea also shows that Malaysia is currently the third largest sand producer in Southeast Asia, behind Vietnam and Cambodia, but almost all of Malaysia's sand is consumed domestically (2017). This insatiable appetite for sand has been filled by an ever-broadening landscape of offshore dredging for the creation of land to build on, and inland quarries, in or along rivers, for concrete (Ashraf et al, 2011; Chee et al., 2017).

### *2.1.1 Environmental Impacts*

Much academic attention has been paid to the environmental impacts of sand mining. The environmental degradation from sand mining can be vast, dispersed, and hard to view from a single angle. With quarry mining, large areas of sandy soil are removed, leaving massive, barren indentations on the landscape (Ashraf et al, 2011). Most forms of sand mining lead to increased erosion in all impacted landscapes, riverine or otherwise (Dissanayake & Rupasinghe, 1996). Widespread mining also exacerbates the impacts of rising sea levels due to climate change as lost sediment in the river system does not reach the delta, causing the settling of sediments and an increased rate of deltaic sinking (Anthony et al., 2015). This has caused the global average rate of sea level rise (2-4 mm) to be aggravated by up to 1.8 mm per year in parts of the Mekong Delta due to decreased sedimentation and settling (Jordan et al., 2019). Furthermore, research has shown that with increased mining, especially in coastal waters, heavy metals that had been settled in the sea bed can become re-suspended in the seawater adding more toxins to the environment and ultimately the food system (Sridhar et al., 2019).

Impacts have also been felt in the biological sphere as well. Sand mining greatly disrupts river systems, increasing turbidity, and destroying aquatic plant life which impacts entire ecosystems. In one study in Malaysia, seagrass nearest to coastal development (ie sand dredging and land reclamation) was the one most harmed (Bujang et al., 2016) Sand mining has been shown to decrease the freshwater biodiversity of fish species in rivers due to increased turbidity (Cooke et al., 2023). The in-stream mining though, not always as apparent, can often cause much broader impacts, spread out further from the initial mining sites. Increased upstream erosion as material is carried downstream to restabilize the system, both from beds and land surrounding rivers has been observed (Hackney et al., 2020, 2021). Ghani et al. explain that sand mining creates environmental dangers for human populations along mined rivers, especially when it comes to in-stream mining (2010). In-stream mining, the process of removing sand from the bottom of a river, exacerbates the risk of flooding by disturbing the morphological equilibrium within the alluvial system (Ghani et al., 2010). This is especially problematic in Malaysia, as there has been a general move, especially along the Muda River towards dredging versus land-based quarrying. This shift has led to many changes in the river system especially when examined from the hydrological angle. According to Ghani et al, the increased sand mining activity has greatly increased the instability of the river banks, increasing the risks of large floods (2010). In addition to this, the current rate of sand extraction from the river system far exceeds the natural replenishment rate of sand within the system, greatly destabilizing the sedimentation process in the river. (Ghani et al., 2010; Harun et al., 2020).

### *2.1.2 Human Implications of Sand Mining*

When examined from a physical geography lens, as shown above, there is a relative wealth of knowledge on sand mining, but much less has been written from a human angle. Much of what has been written though is very insightful into specific communities and their relationship with aggregate extraction. From a global view, sand mining takes many forms and various actors play different roles depending on the region (Padmalal & Maya, 2014). There is also a problem of ownership when it comes to sand. Sand quarries may have clear owners, but sand in rivers and on the sea bed is a different story. Some nations have control over what is taken from these common areas, but many do not. In Myanmar for example, sand mining companies are often awarded mining rights to new sand deposits after floods (Lamb et al., 2019). In other locations, research has been done into what locals think about sand mining in their area and their opinions are usually based on whether the sand mining is improving or degrading their livelihoods. In one study, locals in Cambodia and Vietnam were interviewed to ascertain their opinions on sand mining impacting their local communities. On the whole, most were upset by the process that the government was using to permit sand mining from nearby waterways (Runeckles et al., 2023). Another conclusion was drawn, that many people were unhappy with the lack of local consideration in the granting of mining permits, especially when these permits are for waterways that many directly rely on for food and water (Tambajong et al., 2018). In Southeast Asia, and especially Malaysia, sand mining is completed with heavy machinery rather than artisanally (Lamb et al., 2019; Padmalal & Maya, 2014). Furthermore, another paper links the trends of urbanization to sand dredging and livelihoods created in the West African context around Lagos, Nigeria (Aliu et al., 2022). In their paper, the authors discuss in detail not only the specific environmental impacts of both sand mining and land reclamation but also how many people depend on the sand industry for their income, which is an important consideration when seeking to make this industry more sustainable (Aliu et al., 2022). The majority of the literature concludes that locals who are not involved in the sand industry are being negatively impacted by sand mining, though many papers are beginning to recognize that aggregates are necessary for development and local livelihoods (Bendixen et al., 2023; Lamb et al., 2019; Mngeni et al., 2016). There is a knowledge gap, as there is limited research into human reactions and impacts to sand mining outside of how their environment is negatively impacted, and almost nothing has been written on this topic in the Malaysian context.

### 2.2 Land Reclamation

For this thesis I will use Chapman's definition of land reclamation; coastal reclamation is the engineering activity that converts coastal wetlands or shallow seas into developable land (1984). Coastal reclamation involves many processes, including draining seawater, seawall construction, and filling the enclosed space with various materials such as sand and other aggregates (Chapman, 1984). Land reclamation by draining seawater is common in places, like the Netherlands, but more often undertaken in areas where waters are shallow and calm, whereas deep or open ocean waters are more likely to need to be built above sea level, rather than with dikes (Hoeksema, 2007). Land reclamation consumes massive amounts of sand, but rather than from rivers, this sand often comes from the nearest available source, usually the sea floor (Hoeksema, 2007). Land reclamation has a large impact on marine ecosystems that are not only destroyed by their creation but also reduce the quantity of critical coastal ecosystems, like mangroves, that are some of the most biodiverse places on Earth (Chee et al., 2017; Yee et al., 2010).

Across the world, nations and cities eager to expand have seen the sea as the last great frontier to conquer. As recently revealed by new mapping techniques, east Asia, especially China has been the most vigorous land reclaimer with gulf states not far behind. Southeast Asia only accounted for 3% of global land reclamation as of 2020 (Sengupta et al., 2023). This land reclamation was in part fueled by the country's booming real estate sector and its demand for urban land, up until the recent correction in that market (Cai et al., 2020). Land reclamation is still being undertaken at an ever-increasing rate globally, even with the increased risks of flooding to coastal cities posed by climate change (Tellman et al., 2021). Singapore and the Johor Strait were the largest areas of land creation over the past two decades in Southeast Asia specifically (Sengupta et al., 2023). Singapore, being a small island nation, must import most of its sand for construction and land reclamation with most of it coming from Cambodia and Vietnam, and gulf states often also import sand for land reclamation as well, mainly from Australia (Gavriletea, 2017). Since 2020, the rate of land reclamation has not slowed, especially in Malaysia. Three areas of major land reclamation have been the Johor Strait, Melaka, and Penang Island which have seen rapid development under the guise of economic growth and modernization (Bunnell, 2004; Chee et al., 2017; Cipriani, 2022). Land reclamation has also been key to foreign-funded projects such as Forest City, a Chinese new master-planned city along the Johor Strait (Moser, 2018). The Belt and Road Initiative (BRI), of which Forest City is a connected project, has been one of the largest catalysts for land reclamation across the Indo-Pacific region, as China seeks to expand its global dominance through imposing port projects in or near the sea (Avery & Moser, 2023; Hutchinson & Yean, 2021).

### 2.3 Speculative Urbanization

Speculative Urbanism as a term was first coined concerning Bangalore, India, which was a rapidly urbanizing city in the early 2000s. The process is characterized by a rapid transition from rural economies to a modern world city, a process that entails land dispossession and intense governmental and/or private real estate speculation via a rapid increase in land values (Goldman, 2011). This process is also accompanied by government pressure to develop and attract residents to invest in a new or fast-developing city (Goldman, 2011). The transition from Fordism, or a just-in-case mode of production to post-Fordism, a just-in-time mode of production, and a more decentralized search for profit has empowered firms to partner with governments to speculate on new urban areas to create new hubs for growth (Goldman, 2011; Harvey, 2005). According to Goldman, many cities undergoing speculative urbanism seek to emulate the success of Dubai and Singapore, and in Southeast Asia specifically, look to Singapore as a model, and have attempted to import their success by following their development pattern (2011). The UAE and China have somewhat compiled this pattern and the repeated 'success' of this method has convinced even more nations to adopt a build-first growth model, including Malaysia (Goldman, 2011; Pow, 2014).

One study documents the failure of Forest City, a BRI project, to live up to its promise of being an economic boon for the region, as it has been continuously scaled down and is now partially abandoned. Nevertheless, the local government in Johor has doubled down on projects like it, despite local disdain for Forest City and other developments primarily targeted at Chinese as investment properties (Avery & Moser, 2023). Another study details the massive reclamation of land at the Melaka Gateway project in Malacca. This project was designed to modernize Melaka and provide more developable space for the historic city. Due to the development there, the city is at risk of losing its UNESCO heritage status, and much of the land remains undeveloped as of publication. Most of the sand for this project has been dredged from a nearby sea bed, destroying the local ecosystem as well (Cipriani, 2022). Another study positions the Melaka Gateway in the BRI as it is also a project to modernize the port infrastructure in Melaka, though the project has been very controversial in the city itself as few positive outcomes are visible yet (Connolly, 2023). All three of the articles show how these projects have taken the 'build now, use later' mindset which is central to both Malaysia's historical development and Speculative urbanization as a global trend (Bunnell, 2004; Goldman, 2011). China's involvement in Malaysia through the BRI has weaned over time, as public opinion has turned against China. This is primarily due to the failure of Forest City, but also partially due to China's increased geopolitical positioning in the South Sea against Malaysia itself and its neighbors like Brunei, the Philippines, and Vietnam (Beech, 2018). This is the opposite of the case that has presented itself in China, where there were clear buyers, even if the new construction was not always lived in (Cai et al., 2020).

### 2.4 Research Gap

There are clear, well-documented impacts of sand mining. There are physical impacts such as changing water quality, impacting marine environments, and sediment loss which can cause regional subsidence, especially in deltas. These impacts also implicate people, as they must bear the front of destabilized river systems, loss of fishing stocks, and reduced water quality. Land reclamation also has environmental impacts which are documented, though its human impacts are only beginning to be understood. There is a gap in the literature when it comes to understanding the connections between the three processes of sand mining, land reclamation, and speculative urbanism. I will use the case study of Malaysia's western coastal area over the past 40 years to explore the aforementioned processes. Specifically, I will look in detail at the Johor Strait area around Forest City, Melaka, and Penang Island to examine the connections and the extent to which urbanization has manifested itself both through land reclamation where development is happening and how development impacts are externalized where sand is mined in the Muda River basin. These sites were chosen in particular because of the rapid rate and vast extent to which land is being reclaimed and development is constructed.

# CHAPTER 3: CONTEXT

## 3.1 Geographic Setting

Malaysia is a country of 34 million people in Southeast Asia. Its GDP is $407 billion, giving a per capita GDP of $12,000 (*IMF Datamapper: Real GDP Growth*, 2023). This level of development makes it a middle-income country. The nation itself is split into two main parts. The more rural Eastern Malaysia sits on the island of Borneo, while the more populous Peninsular Malaysia sits to the west. This thesis concerns Western Malaysia, and more specifically the urban regions of Penang-Georgetown, Melaka (Malacca), and Johor, as well as the Muda River Basin as a case study for sand mining in the region. The three urban areas are located along the west coast of Peninsular Malaysia, along the Straits of Malacca. In Johor, the main area of activity with regard to land reclamation is Forest City and several other smaller projects that sit across the Johor Strait from Singapore. In Melaka, the main land reclamation project is the Melaka Gateway, and in Penang, many projects have been undertaken including Andaman Islands with none completely dominant, though the main area of development is along Gurney Drive, on the north side of Georgetown.

*Map 3.1: Map of West Malaysia with Land Reclamation Focus Sites and Muda Basin*

### 3.2 Development History

Forest City is a real estate megadevelopment, described in the literature as a New Master-Planned City, that was financed by Country Garden Holding, a Chinese real estate development firm. It was announced in 2006 in cooperation with the government and Sultan of Johor and is managed under the Iskandar Regional Development Authority. Plans have been significantly scaled back from the initial development plans, which had anticipated great interest from domestic Chinese buyers (Moser, 2018). China implemented strict currency movement restrictions during the project's development and strict lockdowns during the pandemic further exacerbated the project's decline. Forest City was also ostensibly pitched as a part of China's Belt and Road Initiative (BRI), which brought Chinese-backed loans and investments for new infrastructure projects in the Indo-Pacific region (Avery & Moser, 2023; Moser, 2018). After the COVID-19 Pandemic and political fallout of 2022, Chinese investment in BRI projects fell to virtually zero. Due to these circumstances, the Forest City's construction has been halted and many have described it as a 'ghost town' (Avery & Moser, 2023). The project has come under criticism for its impact on the local environment. The project has greatly damaged mangrove and seagrass ecosystems which were once located where the city now stands, as well as around the Straits of Johor which have been greatly impacted by dredging for sand to create the project (Avery & Moser, 2023).

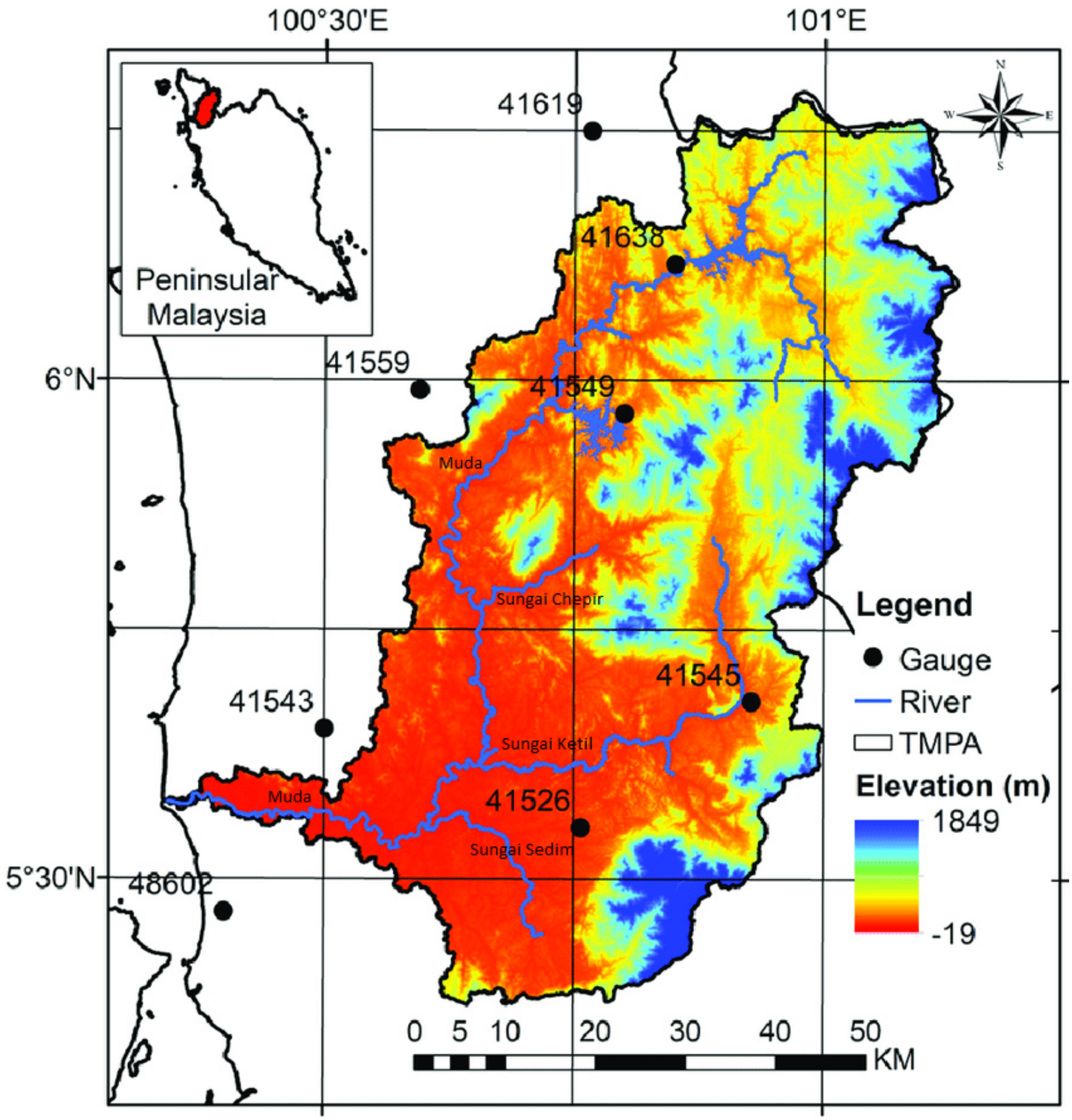
The Melaka Gateway project is a land reclamation project along the coast adjacent to the city of Melaka. It has several phases, including residential developments on artificial islands, a deep sea and cruise ship port, and new areas for industrial capacity (Connolly, 2023). The project began in 2014, but land reclamation around Melaka is not new. Smaller projects were common in the past, but this new project was launched in cooperation with local and state government backing, as well as investment from international sources which were revealed to be linked to the BRI (Shepard, 2020). The project has come under criticism for ecological mangrove and seagrass ecosystem destruction. It has also come under pressure from UNESCO to slow the rate of development, as the city has World Heritage status (Connolly, 2023). The project is also slated to impact the historical Portuguese-speaking population, descendants of the initial settlers who began a colony in Melaka in 1507 (Connolly, 2023; Shepard, 2020).

Penang-Georgetown is a city of 222,000 people (as of the 2017 census) on the eastern side of Penang Island in northwestern Malaysia. Historically the city was one of the key ports for the British Straits Colony and later served as a hub for the tin trade. Due to its place as a port city, many Chinese traders moved there from other British colonies, and later many Indians moved there as laborers. Today, Penang State (both the island and adjacent mainland) is the most diverse state in Malaysia and the only state to not have a hereditary monarch position within its government. The city center of Georgetown is a UNESCO world heritage site, like Melaka (Chee et al., 2017). Land reclamation has a long history in this island city, beginning with the very start of the city in the 1700s up to today. Many areas of the island, including the airport are on reclaimed land that was once sea or coastal wetland. More recently, three large-scale real estate development projects have been undertaken, the oldest and now complete Straits Quay project, Gurney Wharf, a project undertaken by the state government itself, and Andaman Island Project, undertaken by Eastern and Oriental group, who also completed the Straits Quay project (Chee et al., 2017). This island is still under construction but aims to be an ultramodern condo tower development.

### 3.3 Muda Sand Mining

The Muda River is the largest in Kedah State, Malaysia, and one of the largest in the country by discharge. It begins in the Ulu Muda Forest in the mountains along the border with Thailand and travels 180 kilometers to the sea near the town of Kota Kuala Muda (Ghani et al., 2010). The total catchment area of the river is 4210 $km^2$ (Ghani et al., 2010). Sand mining in the Muda River basin has been occurring since at least 1985 and was well established when the first study was completed in 1995 (*JICA*, 1995). Sand from the system is extracted by both direct river dredging and on-shore quarrying of sand deposits (Ghani et al., 2010). Sand mining in the region is mostly driven by nearby urbanization, chiefly by the nearby urban center of Penang. Most of the river mines are held by permit holders, which are granted by the state government (*JICA*, 1995). The larger quarry-style mines are often larger operations, requiring more permitting and acquisition of land. Malaysian law requires separation between the river channel and sand mining quarries to ensure the integrity of the river, though frequent flooding and lack of maintenance often cause these barriers to break, which then impacts the morphology of the river (Ghani et al, 2010; *River Sand Mining Guidelines*, 2020). Direct river sand extraction has long been known to be a cause of exacerbation of flood damage, and reduction has been recommended since 1995 (*JICA*, 1995). Sand mining in the region is expected to remove 0.5 to 1 million $m^3$ per year, and the natural replacement rate into the river is 5 to 10 thousand $m^3$ per year (*JICA*, 1995). In the region where sand is mined, common industries include oil palm and chicken farming.

*Map 3.2: Map of the Muda River Basin*




Caption 3.2: Branches of the Muda are labeled, the largest tributary is the Sungai Ketil, followed by the Sungai Sedim with the Sungai Chepir being the smallest. Source: (Tan, 2019).

# CHAPTER 4: METHODOLOGY

## 4.1 Methods Introduction

This project combines both GIS and fieldwork analysis of Malaysian sand mining, as well as land reclamation to assess the synergies and connections between the two anthropogenic processes. A combination of both qualitative and quantitative data was collected to analyze the who, where, and when of sand mining and land reclamation in western Malaysia. On the ground, mainly qualitative data were collected to provide context and information where quantitative data was not available. As sand mining is a difficult process to track, using both on-the-ground knowledge and remotely sensed methods made the most sense in this case.

## 4.2 Field Work Methods

I assessed the field in several distinct stages while on the ground in Malaysia. The first was while as a participant in GEOG 425, McGill's Southeast Asian field studies course. As a student in this two-week-long course, I had an opportunity to observe both the speculative urban development projects, as well as the local population that was being pressured by the rapid urbanization process. This began in Johor, directly across the strait from Singapore (between 10 and 20 kilometers away). With this class, I visited a local village, Kampung Sungai Melayu along the Johor Strait. During the last leg of the Johor visit, we visited Forest City, the largest land reclamation development project in Johor. Here I observed the saleroom, aesthetics of development, and their eco museum. While there I also observed the overall aesthetic of the development and took many images as well as speaking to other visitors who had come to see the megadevelopment.

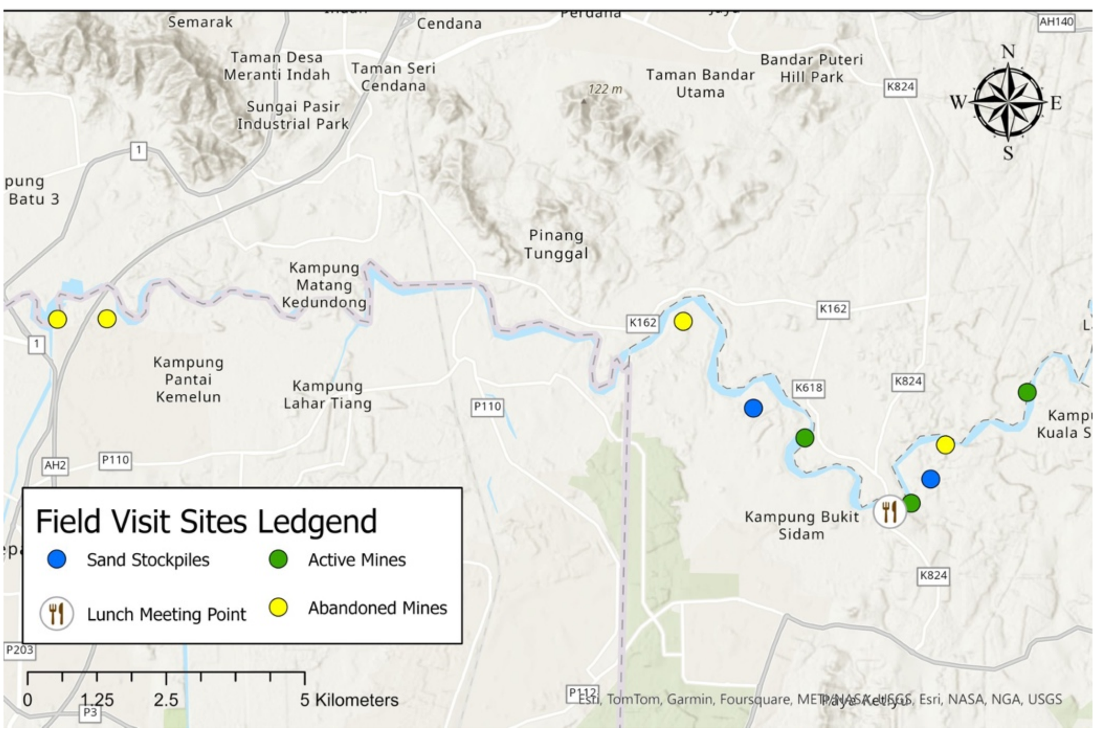
The next leg of the trip brought us to Melaka (Malacca), a city about halfway between Singapore and Kuala Lumpur along Malaysia's west coast. As part of the field trip, the class visited a completed part of the Melaka Gateway (southeast of the harbor), as well as a part that has yet to be developed (on the northwest side of the harbor). This project consists of reclaiming land along the ocean and eventually developing it to boost the economy in the region. Here I also mainly took pictures and notes for qualitative data to add context to my further findings. While at a dinner organized by the trip's coordinator with a man who runs a small historical society in Melaka, he shared historical accounts of Melaka and the new gateway project. After the presentation, I spoke with him one on one to get more detailed information about this which added further context to this project and helped to add local context to the impact this project was having on locals in Melaka. On our final day in Melaka, we visited the newly constructed portion of the Gateway project, which at the moment is a massive sandy space with very little construction on it. Again, I stayed in public areas and took images and notes as observation techniques.

The final leg of the field trip brought me to Penang-Georgetown. Penang is the island that the city of Georgetown is built on, and for the purposes of this thesis, I will refer to the whole thing as Penang or Penang Island. There is also a State of Penang which includes part of the mainland, and when speaking of that area, I will refer to it as Penang State. In Penang, I visited a new land reclamation project along Gurney Avenue, on the north side of Georgetown. There have been several phases of this project, one that is finished and now known as Straits Quay, though it is still trying to sell units. Two other developments have been undertaken after this initial phase, one reclaiming an island off the coast of Penang, known as Andaman Islands, and another further southeast of Gurney Wharf. This project is closer to downtown Georgetown. These two projects are still actively reclaiming land, and I was able, through photos, to observe sand trucks entering both projects. I also received photos and secondhand information from my reader and field trip coordinator, Dr. Moser, allowing me to further my analysis of these Penang developments.

Finally, after the trip had concluded I was able to venture inland to visit the source of some of the sand being used to create these land reclamation projects. For this, with my professor, Dr. Moser, and a helping colleague, Clémence Renault, and I set off to collect more photos, conversational and firsthand evidence to help me complete my research. To do this we hired a taxi driver for the day, who agreed to drive us wherever we requested for the next eight hours. We began in Penang State, investigating older sand mining pits near Kampung Tanjung Rambai. These pits were identified for a previous research question, asking if old sand pits in this region are being reused for aquaculture, though they also present an interesting look forward to what the current area of heavy sand mining could look like in the future.

From here we ventured further upstream along the Muda River, to Kubang Cherok, about 15 kilometers east of the initial sites in Kampung Tanjung Rambai. At this point, we had left Penang State and had entered Kedah State. In a village known as Tanjung Belit, we visited an abandoned quarry, though not as old as the prior mines in Tanjung Rambai, and a sand storage area, a large area near many mines where sand is deposited and then picked up and sent out. After that, we stopped for lunch at a small roadside lunch stand. Here we observed local people, many of whom arrived in sand transport trucks. While there, we met a friendly local. The man was very kind and a sand truck company owner with three trucks. He offered to show us to the mines around Bukit Sidim, many of whom he transported sand for, and we happily obliged. He brought us to an abandoned quarry that had been impacted by flooding and we observed a dredging operation from this barrier which was located just downstream of the first rapid on the Muda River. We then followed him to another dredging operation, which was one of his current sand sources. We visited one more site with him before concluding our tour with him by having tea. Dr. Moser, Clemance, and I visited one more sand quarry further upstream, before concluding our sand mine tour. At all the sites we took photos, and where appropriate I recorded key interactions with the sand truck company owner and our taxi driver in writing.

*Map 4.1: Sites Visited during Muda River Fieldwork*




Caption 4.1: Sites on the Lower Muda River visited on 22 May 2023. All are along the lower stretch of the Muda River, about 40 km from Georgetown-Penang.

## 4.3 Remote Sensing Methods

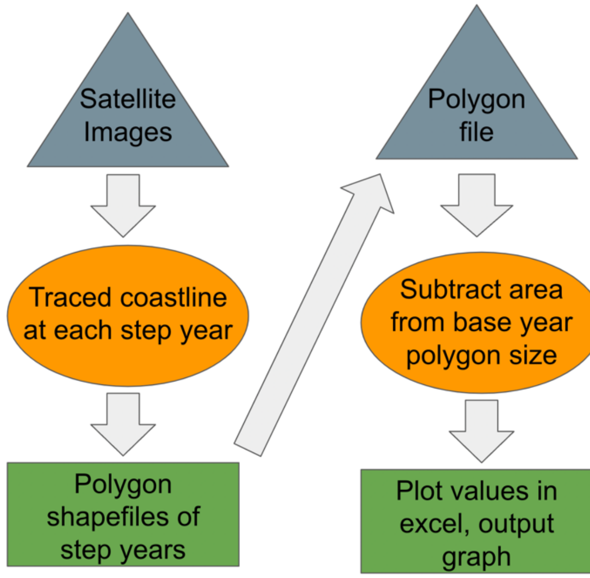
For the second part of my analysis, I analysed the extent of land reclamation as well as active sand mining and stockpiling sites using remote sensing imagery from Landsat and Airbus obtained through Google Earth and analysed in ArcGIS Version 3.3.1.

### *4.3.1 Land Reclamation Quantification*

For mapping land reclamation on the west coast of Malaysia, I relied on historical Google Earth satellite imagery. In Google Earth Pro, I used the polygon tool to map the coastline of Penang Island, Melaka, and two areas along the Johor Strait, one near the causeway connecting to Singapore and the other in the vicinity of Forest City. For Penang Island, there was satellite imagery with enough detail to place the coastline reaching back to 1985, so this is the start year for my analysis of that area. Moving in five-year increments, (1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2023) I traced the coastline in Google Earth Pro creating a polygon of the island for each year. I repeated this process for each of the other locations, though for the Johor Strait locations, the exact measurements for the earlier years were difficult to ascertain due to the poor image quality, and there was relatively little activity in this subsection of my study until the year 2000. There could also be some slight discrepancies due to the placement of points that define the coastline.

After creating the polygons in Google Earth Pro, I imported these files into ArcGIS. I then exported the files from Google Earth Pro to ArcGIS, requiring a change in file format from .kmz to shapefile. From here, I layered these files for each area from oldest at the top to youngest at the bottom, so that when viewed, the additional area reclaimed after each interval was apparent from the graphic (see Map 4.1). Taking all the polygons from each section, I combined them into one layer using the merge tool. This tool preserves the initial layers and creates a table of all the input layers. Taking these resultant tables, I exported them to Microsoft Excel for further analysis. In Excel, I began by converting the area result, presented by ArcGIS in square meters into square kilometers to make the scale more comprehensible. Then I combined all data from each of the three sites analyzed to create final figures and graphs with equalized years to analyze the resultant data.

*Figure 4.1: Flowchart of Quantifying Land Reclamation*




*4.3.2 Sand Mine Mapping*

For the second part of my GIS analysis, I tracked the proliferation of sand mines over time. This second step was not as easy to collect as the coastline temporal changes, as individual sand mines are quite small and very numerous across the Muda River and its three main tributaries the Sungai Sedim, Sungai Ketil, and the Sungai Chepir. To determine if a site was an active sand mine, I looked for five factors (see Figure 4.2). These five qualities are quarry-like appearance, dredging pipes, excavators, drying piles or stockpiles, and a sandy access road to the mining site. These are important indicators because dredging pipes, excavators, and drying/ stockpiles will indicate an active mine. The other two a quarry appearance and sandy access road are easier to spot and indicate mining, but will persist even if no mining is occurring. If five or four of these aspects are present, then I was very sure that mining was taking place at the time the image was taken. If only three were present, I marked them but paid close attention to other factors, like if there was visible growth to quarries or morphological change to the river (for river dredging sites) compared with the closest satellite images. Finally, if there were only two or one of these qualities present, I was quite sure that the mining site was inactive and thus was not marked.

*Figure 4.2: Example Sand Mine Quality Chart with Photos*

Sand Mine Key Characteristics Chart

| | Quarry Appearance | Dredging Pipe | Excavator | Drying/Stockpiles | Sandy Driveway |
|---|---|---|---|---|---|
| Photo 1: Present **YES** | Y | Y | Y | Y | Y |
| Photo 2: Present **YES** | N | Y | Y | Y | Y |
| Photo 3: Present **NO** | Y | N | N | N | Y |
| Photo 4: Present **MAYBE** | Y | Y | N | N | Y |

Caption 4.3: Green marks likely sand mining also indicated blold YES at the left, yellow means possible sand mining, indicated MAYBE, and red, indicated NO means no active sand mining at that site. Y or N marks indicate whether each critieria is present in the picture.

*Figure 4.3: Photo of Mine 1*

Caption 4.3: Mine with all five of the features I identified as qualities of active mining *(5°32'42"N 100°33'16" E)*. Airbus 2023.

*Figure 4.4: Photo of Mine 2*


Caption 4.4: Dredging mine with 4 qualities (5°45'02"N 100°39'32" E). Airbus 2023.

*Figure 4.5: Photo of Mine 3*


Caption 4.5: Quarry Mine without active mining, two mine qualities (5°38'55.9"N 100°39'42.9" E) Airbus 2023.

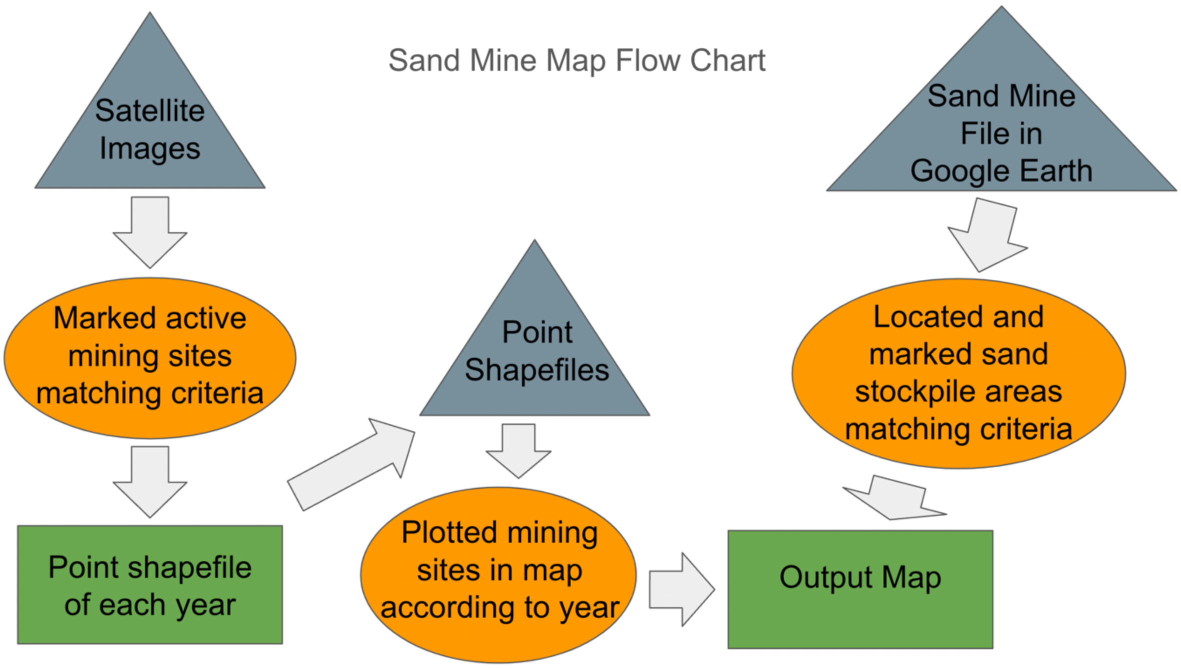
*Figure 4.6: Photo of Mine 4*


Caption 4.6: Quarry with active mining likely, though some uncertainties (5°32'56.5"N 100°40'00.4" E). Airbus 2023.

The first year that Google Earth Pro had reliable data for was 2008, and following 5-year temporal windows again (2008, 2013, 2018, 2023), I mapped out all of the sites present in each year. Some of the data was not available from these years exactly but was available within 6 months of the year (July the previous year to June of the year following) and was used as a proxy (details on this are discussed in section 6.4). From these files, I imported them into ArcGIS Pro and merged any files so that a clear year-by-year set could be completed. To complete an analysis, I needed to acquire a shapefile for the rivers that I chose to map sand mines along. For this I chose the main branch of the Muda River, moving upstream from the mouth until the furthest upstream mine was detected. I also chose to analyze a tributary of the Muda, the Sungai Sedim, as it was noted by Ghani et al. as another major source of sand in the Muda Basin (2010). To acquire the shapefile, I used the Open Street Map plugin in QGIS and imported the file to ArcGIS. Figure 4.7 outlines this process in schematic form.

Using both this river file as well as the mine site files, I created a map showing the progression of mines. There seems to be a trend present, but after consulting with GIS specialists in the Geographic Information Centre, there appears to be no clear tool to use to quantify this. I will present a map of the locational data in the results section.

*Figure 4.7: Flowchart of GIS Methods for Mapping Sand Mines and Stockpiles*




*4.3.3 Sand Stockpile Mapping*

Finally, I located the positional of large sand stockpiles located in the Muda Valley, using a similar method to that used in the mines. To track these, I am looking at sand stockpiles that were created quickly and were then drawn down over a longer period. To do this, I created four qualities that would determine whether a pile was a sand stockpile just an inactive site, or something else entirely. These qualities are a large size, either covering many pixels on a satellite image or shadows visibly created due to the height of the piles, not having a flat top, and distance from the active mining site, as these piles should not be directly in the actively mined sand if it were being used for a stockpile and changing size over time. If there were 3-4 of these qualities, then the pile was likely a stockpile, and otherwise, they were likely a non-stockpile of sand. I excluded sand piles with a flat wide appearance, as from field work, these are used to dry sand rather than store it. The specific images used for compiling the sand mine and stockpile data are located in the appendix.

### 4.5 Positionality

As a researcher, it is important to examine the situation as an outsider and how it can impact data, especially qualitative, that is collected in the field. I am not Malaysian and had never been to the country before making this trip. I spoke only a few essential words, and without Dr. Sarah Moser's help as a translator, the field portion of this thesis would have lacked the critical details. Also, as an outsider, I do not understand the culture surrounding the communities where sand mining and land reclamation are taking place. To prepare I studied some basic Malay phrases, as well as reading about Malaysian society and government. I also spoke with Dr. Moser about good field practice due to her extensive field experience in this part of the world. The 'Bumiputra' or local people were incredibly hospitable during my time in the field and were more than happy to share almost anything regarding the sand trade. I asked only objective questions to ascertain a social understanding of the sand trade, though as a non-Malay speaker, I have no idea whether these questions were seen as invasive or insensitive, other than to observe the reactions and responses from people I interacted with.

My positionality regarding the people I interacted with and excerpts of conversations I collected is important to understand. I made sure to never ask any personal questions and made it clear that all questions were voluntary. Any personally identifiable information was not collected, and any answers were general and factual, as this was the aim of my thesis. I used some of these answers to confirm trends I observed in the field as well as from remotely sensed data.

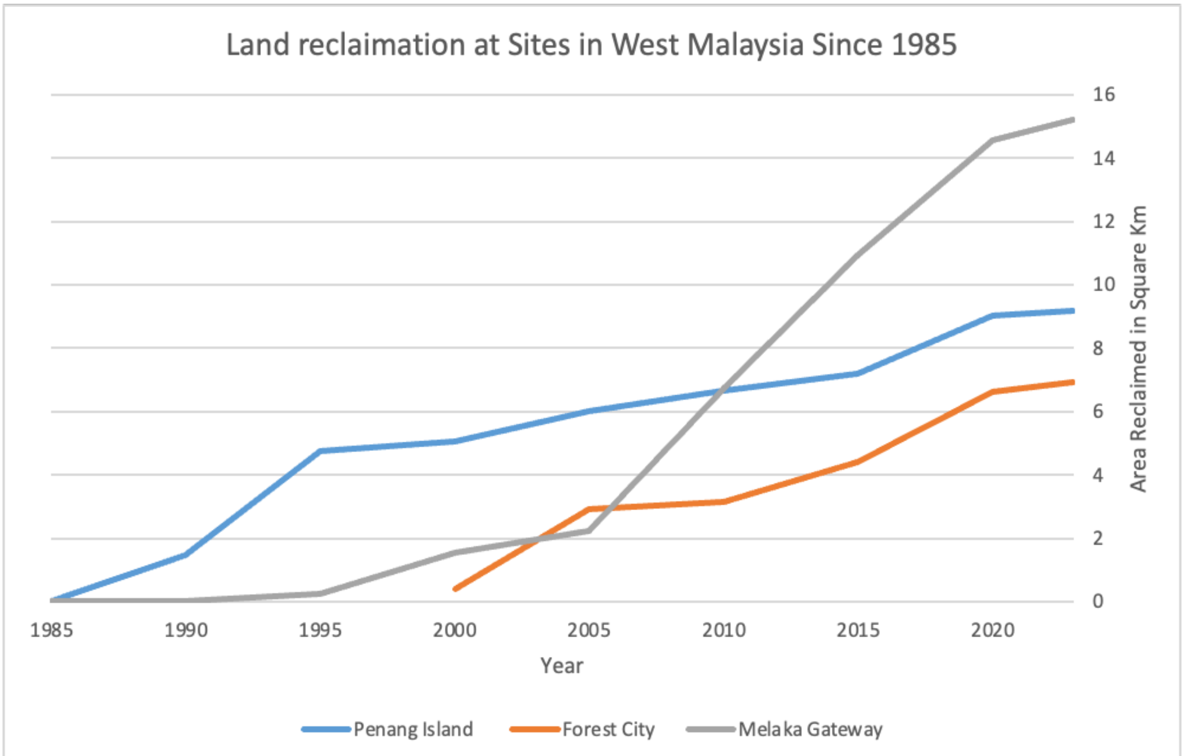
# CHAPTER 5: RESULTS AND ANALYSIS

In this chapter, I will detail all results from my research, both quantitative and qualitative. My fieldwork yielded mostly qualitative results that helped to fill in missing details in the overall story of sand mining in the Muda River. My remote sensing research focused on quantitative occurrences, both in land reclamation and sand mining in western Malaysia. I will introduce results in this chapter by research question and will only present and analyze to the extent that I can with confidence. Using the methods outlined in the last chapter I will attempt to answer the research questions I outlined in Chapter 1. This chapter will be split into three sections to address each one of these questions, providing concrete results as well as analysis. I will reserve my thoughts for the discussion chapter.

## 5.1 Land Reclamation Projects

In this thesis, I set out to determine how much land was reclaimed at Forest City, Melaka Gateway, and on the Island of Penang. Through literature and field visits, I identified these three sites as the three areas that were seeing the most land reclamation in Malaysia, and thus constitute most of the activity that is actively reshaping the coastline. Through my GIS analysis by tracing satellite imagery, I determined that around 31 km² was reclaimed across the three regions from 1985 to 2023. The area around Forest City and the Johor Strait had very little land reclamation, if any at all in 1985. Melaka had begun to reclaim before 1985, but due to the lack of imagery before then, the exact amount is hard to quantify. Penang Island has the longest history of land reclamation across the three areas, but before the modern era, reclamation was undertaken on a small scale. Penang's growth in percentage is the smallest of the three regions, but very significant nonetheless. Each site saw a varying amount of land reclamation, ranging from only 7 km² in Forest City, 9 square kilometers on Penang Island, and 15 km² at the Melaka Gateway project.

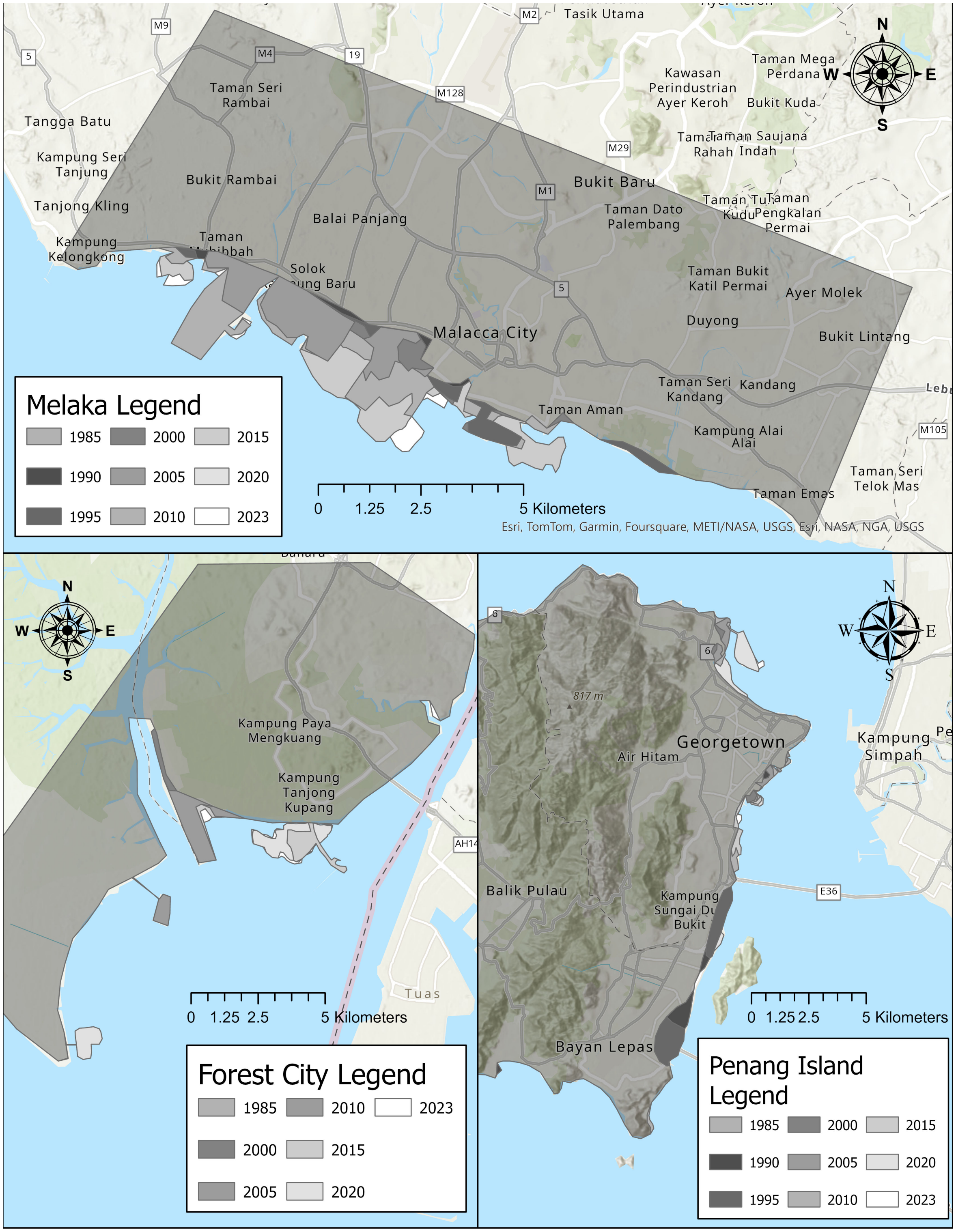
*Figure 5.1: Growth of Land Areas in Respective Land Reclamation Sites over Time*




5.1 Caption: This graph shows the area reclaimed across the three study sites in km². Data was sampled every 5 years from 1985 and ending in 2023. Data from Landsat, Airbus, and Maxar provided by Google Earth. No Data in Forest City before 2000.

As shown in Figure 5.1, land reclamation rates over time at all sites have trended up, though this is to be expected, as land reclamation is an inherently gaining process. More interestingly are the rates of increase over time as they correlate with major shifts in the economic trends of Malaysia and the world. The most major trend present in the data is how the COVID-19 pandemic impacted the rate of increase in reclamation across all sites. This is to be expected, as the economy slowed around the world, and so did supply chains, including domestic ones for sand.

*Map 5.1: Expansion of Coastline in Melaka, Forest City and Penang Island*

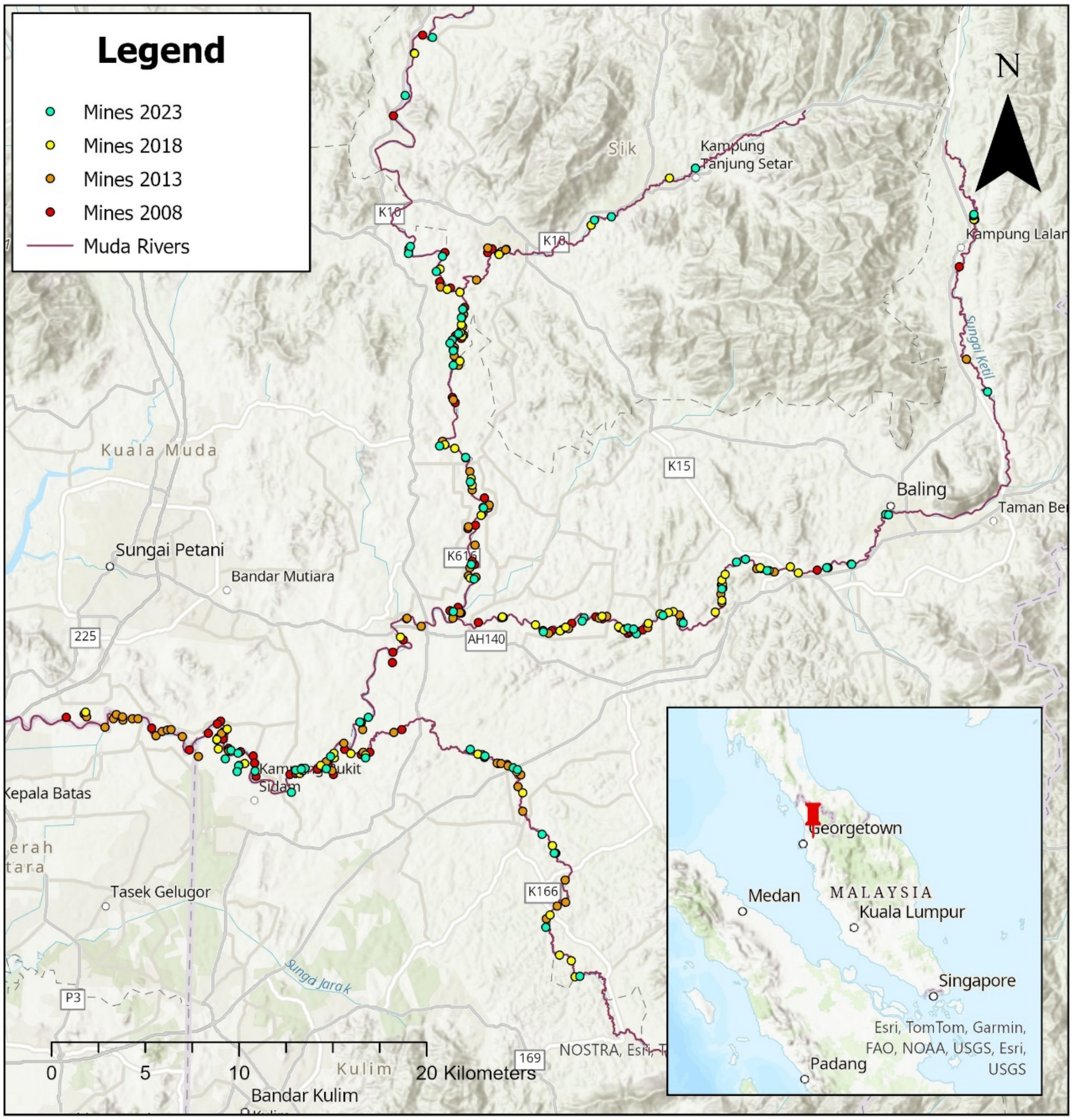



Map 5.1 Caption: Melaka Gateway, Forest City, and Penang Island landmass expansion through reclamation from 1985-2023. The areas of these maps are created in Figure 5.1. 1985 landmass is the base year and may include reclaimed land. Note: Forest City region had no data until 2000 and western side of Penang Island had no land reclamation, so it is not shown in the figure.

## 5.2 Sand Mining in the Muda River Basin

Sand Mining in the Muda River is widespread and has been occurring for many decades. In recent decades though, the rate of sand mining has caused widespread morphological change and ecological damage to the system. Using my method of manually pinpointing each sand mine, I was able to locate 300 active mining sites over the fifteen-year survey period, though this includes sites that were active for more than one year. There were 76 in 2008, 90 in 2013, 67 in 2018, and 67 in 2023. Though mine numbers may be getting fewer over time, the intensity of mining has not slowed. Mines in the later years are more likely to be quarry operations and some quarries merged and became one mine site, thus decreasing the overall total. The trend of mines merging again shows the depletion of sand deposits along the river. Though I tried several statistical analysis methods, I was unable to make any of them produce discernible results, so I will simply present the map here.

*Map 5.2: Locations of Active Sand Mining in the Muda Basin.*




Map 5.2 Caption: Mines identified and mapped from each of the survey years (2008, 2013, 2018, and 2023). Rivers files sourced from OpenStreetMap.

The main finding of sand mining mapping is that there is a clear upriver trend in the location of sand mines over time. The lowest sand mines on the river, seen on the downstream reaches of the system have mostly been completely abandoned, except for the largest quarries, and smaller in-stream dredging mines exist much further upstream today than they did even fifteen years ago. There was one exception to this, in 2013, there was a large amount of sand dredging sites along the lower Muda River, though this appears to be the result of a flood that moved more sediment into the lower sections of the system. Another interesting trend in the data is how well river size tracks sand mining activity, with larger rivers being mined more readily than small ones. The Sungai Chepir, the smallest branch of the river, clearly has the fewest number of sand mines, with only 11 active sites over the survey period. The main branch of the Muda has the highest concentration with 168, and the Sungai Ketil and Sungai Sedim have high concentrations as well with 82 and 39 locations respectively.

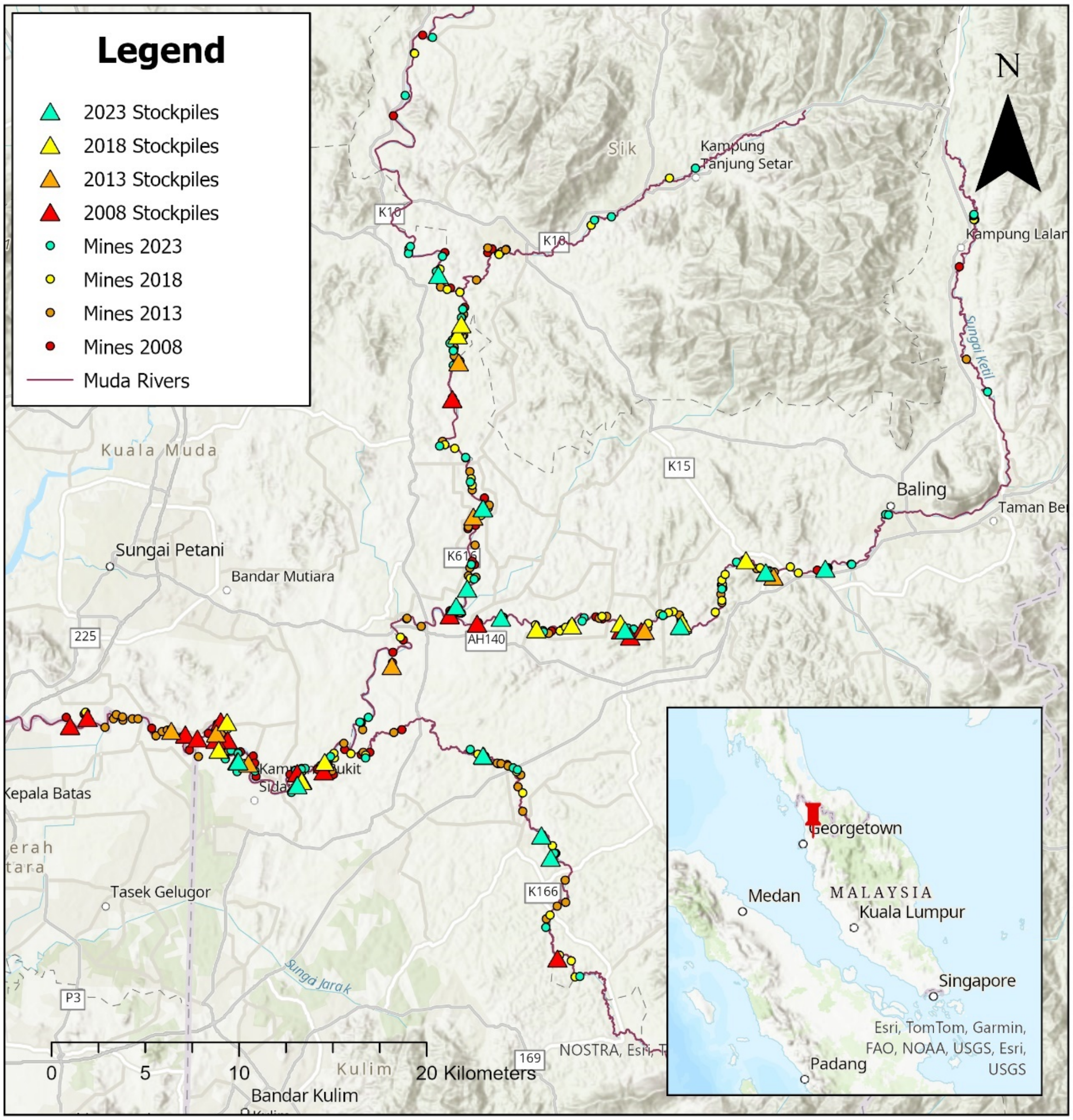
From fieldwork conversations I had with local sand miners, I learned that almost all sand extracted in the Muda River is destined for Penang. This statement in combination with observations I made when surveying the Gurney Wharf land reclamation site in Penang, I observed trucks that look almost identical to those I saw leaving sand quarries along the Muda River. In speaking with sand truck operators as well, they confirmed that sand is being used for both construction and land reclamation. I believe I can conclude that if it is not the sole destination for Muda sand, then it is at least the principal one. With this strong demand for sand and the trend of upstream sand extraction sites, it is possible to conclude that the rate of sand extraction from the system is vastly higher than the natural rate of replacement into the system. This pattern of extracting a resource from the most convenient to that further away is seen in almost all mining industries, and it is logical for sand mining to follow a similar trend. Another interesting finding is that many sand mining sites, especially the out-of-river sand quarries may be mined, abandoned, and then later mined again, sometimes even up to ten years after being initially abandoned.

*Figure 5.2: Sand Truck entering Gurney Wharf*

**5.3 Sand Stockpiles**

In seeking to answer my last research question, concerning whether sand in the Muda River basin is being extracted speculatively. This is a very hard trend to prove empirically, but by combining both on-the-ground and remote sensing methods, I was able to track and map, as well as come to a few preliminary conclusions concerning this interesting trend.

*Map 5.3: Map of Sand Mines with Sand Stockpiles from each Survey Year*




Caption 5.3: This map shows stockpiles as triangles.

As with the sand mines, it was not feasible to use a quantitative method to track any trend in the location of sand mines concerning distance upstream. But visually inspecting the map shows us that there is a somewhat greater number of newer stockpiles upstream and older ones downstream. This makes sense, as stockpiles are located at only the most intense mining sites, where extraction is greater than the rate of sale. The number of stockpiles is remaining relatively stable over time but is slightly declining. In 2008 there were 18 stockpiles, and in 2023 there were only 14. The fewest was in 2013 with only 13. As the mining has moved upstream, mines have trended smaller, though this is not a set rule. During fieldwork, I was able to visit two stockpile sites, one of which was being used as a temporary holding facility, and the second was being drawn down.

*Figure 5.3 Active Sand Stockpile image from Fieldwork.*

Caption 5.3: Sand stockpile located at 5°32'47.7"N, 100° 32' 57.2"E, new sand being held on the left, older stock with vegetation on the right, and located near a large quarry complex.

*Figure 5.4: Sand Stockpile image from Fieldwork*

Caption 5.4: Sand stockpile located at 5°32'06.7"N, 100°34'40.4"E. This pile was being drawn from and not actively restocked. Located near a large quarry complex.

Both stockpiles tell different stories. The stockpile seen in Figure 5.3 is still being added to as well as being extracted from. The mine located adjacent to it was active at the time of the visit and they may have been using the stockpile site as both a drying and stock site. The second stockpile was extracted over a very short period, while the adjacent sand mine was being quarried and its stockpile has been getting smaller since. I can say with confidence that this stockpile was extracted with the knowledge that the sand would eventually be sold. The sand mine operators know that sand is an in-demand material and all sand mined will eventually find a buyer. In the case of this mine, it made more sense to extract at a higher rate than demand, while some mines with less land must operate just at the rate of demand. I cannot say with confidence if sand is being extracted speculatively across the basin, but in specific cases such as the pile in Figure 5.4, sand was extracted with the future knowledge of sale.

# CHAPTER 6: DISCUSSION AND CONCLUSION

## 6.1 Key Findings

The first key finding of my research is that a significant amount of land has been reclaimed over the past 39 years in Malaysia (see Map 5.1). The coastal morphology has been greatly impacted due to this reshaping. In both Melaka and Forest City, these reclaimed sites are located on seagrass and mangrove sites, which have been greatly changed due to the ongoing anthropogenic processes in the area (Avery & Moser, 2023; Chee et al., 2017). The other key finding is that sand mining is moving upstream over time. Though I only have 15 years of data, the JICA report from 1995 confirms the cause of this trend, the overexploitation of sand resources in the river. In the following sections, I will comment on and explore trends in my findings and how they relate to the broader published literature. I will then comment on some shortcomings of my methods and conclude with directions for future research.

## 6.1 Fieldwork Discussion

Sand mining in Malaysia is seen as an industry like any other, something at first I failed to see. In the regions where it is completed, it is often the most lucrative job available. This industry is faced with the same socio-political system as any other in Malaysia. This system is based on the presence of three races, the local Malay people or 'Bumiputra,' Chinese, and Indians. Wealth is not spread evenly among these groups, as local people were the lowest in society until independence in the 1960s. The government since independence has favored the Bumiputra to make a more equitable society (Bunnell, 2004). This pattern can be seen in the sand mining industry. During fieldwork, several larger quarry sites had Chinese names, whereas all of the river dredging operations were run by Bumiputra. Due to lack of time in the field, I was unable to conclude anything from this trend, but it seems quite logical that the river dredging permitting, which is run by the government would favor Bumiputra, whereas quarrying which requires the acquisition of land, would favor the wealthier Chinese minority. Despite these trends, corruption also plays a role in who receives permits and who does not (*JICA*, 1995).

Another finding from fieldwork was the complexity of the industry. Each sand mine is owned by an independent entrepreneur, and they may employ up to seven people, though dredging operations are smaller. Each site (at least the ones I visited) has new equipment: including excavators and pumping apparatus. From each site, sand is piled and dried and then shipped by independent trucking companies. These companies bring the sand to its final buyer who pays at the time of my research in May 2023 1000 Malaysian Ringgits per truck, 35 per tonne of sand, or about $300 CAD per truckload. These trucks will make 3-4 trips back and forth from the mine to Penang (60-80 km each way) and back per day and there are hundreds of trucks, either owned by trucking companies or independent truck owners making these trips. Finally, the entire sand industry in the region spurs secondary economic activity, such as all-day restaurants, which I learned are a rarity in rural Malaysia. These restaurants cater to truck drivers and mine workers alike. In the case of the one I visited during fieldwork; it was owned by the sister of a trucking company owner who was also related to a river sand dredging permit holder.

### 6.2 Trends in Remotely Sensed Results

Demand for sand is mostly driven by the real estate development sector as it is a main ingredient in concrete and glass fabrication, and in the Malaysian case, also for land reclamation. When the world economy ground to a halt in 2020, the construction sector followed suit (Ng, 2020). However this pause was short-lived, and construction resumed quite quickly in Penang and Melaka. In Forest City, the project most dependent on China for investment, the growth after the pandemic has been very low, and land reclamation in the area post-pandemic has been at other sites, such as a port that was expanded in the area, rather than in Forest City itself (see figure 5.1 and Map 5.1) (Avery & Moser, 2023). Sands have also been shifting around Forest City. This shifting is extending spits in downwind areas, forcing more sand to be deposited in areas where erosion is present, changing coastal morphology but not changing overall land area by a quantifiable amount.

Secondarily, the expansion rates of land reclamation also show the effect of the Asian economic crisis in 1998, which created a recession in much of Southeast Asia (*IMF Datamapper: Real GDP Growth*, 2023). This recession's impact is most pronounced in Penang, where a strong rate of land reclamation growth up to 1995 was interrupted and slowed greatly until well into the 2010s. This impact was most widely seen in the speculative and high-end housing sectors, which from on-the-ground research are those most likely to be built on reclaimed land. Reclaimed land often becomes the most prime real estate in the city, especially in places like Penang where the waterfront attracts the largest developments.

Melaka is somewhat different from both Penang and Forest City, as it was less affected by both crises. When the Asian financial crisis was happening, land reclamation was in its very early stages, and it slowed between 1995 and 2000. The largest land reclamation project underway at any of the three sites, the Melaka Gateway broke ground in 2014 and has been moving at a very fast pace since. This is not the only project in Melaka, but it is the most ambitious and the one with the most direct links to China via the BRI (Connolly, 2023). It was again impacted by the pandemic, but because the project has governmental backing and is aimed at improving the regional economy by attracting domestic investment, the slowdown was not as pronounced as in Forest City.

While conducting my survey to create the map of sand mining (Map 5.2) I noticed that sand mines are concentrated in some regions and not others. This was more prominent with quarry mines outside the river. This is due to the river's geology and morphology. Generally over time, sand will deposit in areas of the river where flow slows, and the elevation drop of the river is very minimal. The carrying capacity of water is high in areas of high velocity, and decreases as speed drops, thus in these areas, rivers deposit their bed loads including sand (Ghani et al., 2010). Between areas of rapid flow, sand deposits, and these areas have been the most exploited, especially for sand quarries. In-stream sand dredging is more random, occurring where sand deposits (*JICA*, 1995; Ghani et al., 2010). The Malaysian government knows that sand mining at this scale upsets the balance of sediment flow in the river. They specifically ban in stream sand mining within one kilometer downstream of any bridge, to prevent changes to the base of the channel (*River Sand Mining Guidelines*, 2020). They also know from the 1995 JICA report that sand mining activities are exploiting sand at 100 times its natural replacement rate (5-10 thousand $m^3 * year^{-1}$) within the Muda River which is destabilizing the system leading to environmental and property damage (*JICA*, 1995). There are major problems in the Muda River system that will persist unless changes to the current sand mining operating procedures change.

Another key finding of my research is the extent and rate of expansion of the sand mining sector in the Muda Basin. My analysis shows that given the pattern of expansion, the rate of sand extraction from the rivers is unsustainable in the long run. Because the rate of sand removal from the system is larger than the natural replacement rate, this has caused sand extraction to move further and further upstream over time, especially in-stream sand dredging (*JICA*, 1995). Out-of-channel sand quarrying is more stationary, partially due to the larger operation size, and not being dependent on the alluvial system for new input of material. These sand quarries are also likely to go through periods of being closed in their life cycle, being mined, and then abandoned, likely due to fluctuations in demand for sand.

Sand quarries are very prominent across the Muda Basin and due to their large size, are likely the source of the majority of sand coming out of this region. Malay law requires these mines to always remain separated from the main channel, but during my Google Earth surveys, I noticed that many of these quarry desperation levees eventually erode, allowing the main channel to flow through the old quarry (*River Sand Mining Guidelines*, 2020). In heavily quarried sections of the river, this process has a massive impact on the morphology of the river's channel. These changes in river flow also create new sinks for sediment in the river, removing even more baseload that could have been transported downstream to replenish the system.

*Figure 6.1: Mine on Sungai Ketil during Active Mining*

Caption 6.1: Image from 5/29/2010 Maxar at 5°36'57.12"N, 100°45'11.22"E. Pre-Channel change.

*Figure 6.2: Mine Post Abandonment*

Caption 6.2 Image from 3/15/2015 Airbus at 5°36'57.12"N, 100°45'11.22"E. Mine abandonment, but no channel change.

*Figure 6.3: Levee Breach leading to Meander Cutoff*

Caption 6.3: Image from 4/8/2018 Maxar at 5°36'57.12"N, 100°45'11.22"E. Levee breach, sedimentation present in a flooded quarry.

*Figure 6.4: River using new Cutoff Path and more Sand Mining occurring*

Caption 6.4: Image from 11/3/2023 Airbus at 5°36'57.12"N, 100°45'11.22"E. Post-Channel change, new sand mine present in new channel.

The sites presented above are not an isolated occurrence in the Muda River basin. There are at least 10 locations across the basin where over the course of 10 years or less the river has cut off due to human sand mining and bank erosion. Two processes are impacting this process, firstly, the sand quarries themselves which remove material and make the levees along the river unstable. Secondly, the ongoing sand mining in the river system destabilizes the banks and beds, accelerating erosion (Ghani et al., 2010; Harun et al., 2020). This makes the river more able to erode everywhere, including the levees along sand quarries. This process also makes flooding damage more unpredictable further spreading the negative externalities of development via sand mining.

### 6.3 Speculative Development with Real Damage

As outlined in Chapter 2 'Literature Review' and Chapter 3 'Context,' the developments I tracked for this thesis follow a mode of development similar to that described in the literature as 'speculative urbanism' (Goldman, 2011). This has been commented upon in the literature for all of the sites surveyed by the Land Reclamation portion of my research, though the exact term may not be used (Avery & Moser, 2023; Chee et al., 2017; Connolly, 2023; Moser, 2018).

Spending time in the field examining empty sandscapes of Melaka with half-constructed concrete shells or entire neighborhoods in Forest City abandoned due to lack of buyers, or Penang's seaside highrises that are overshadowing the existing residents, made me step back and ask what the goal of such large scale development. These developments seem to be constructed for construction's sake, and these projects have real impacts. As mentioned previously, the local environment is impacted by dredging activities for large land reclamation projects, but my thesis has shown that this damage is not just local, it is often externalized to locations where resources are extracted (Chee et al., 2017). No sector better typifies this than the sand mining industry. Sand is demanded to fuel these speculative developments at all stages of progress, from the land they sit on to the walls of the towers that will be built. These developments may not find buyers, but the sand is still consumed. The sand industry fueled by this speculative demand is depleting the Muda River far beyond its natural replacement rate. As seen with the stockpiles, the land is depleted preemptively due to the massive demand. The residents of the Muda Basin will have to endure the consequences of speculative development policy, whether economic benefit for foreign investors, sultans, and urban areas is produced or not.

*Figure 6.5: Sandscape of Melaka Gateway*

### 6.4 Limitations

The methods and data I used to compile this thesis are not perfect. First off, as I already alluded to, I was unable to find a suitable GIS technique to assess if there was a quantifiable upriver trend to mining activity and stockpile placement. Because of this, I was forced to analyze this section qualitatively only. To be fair, it does seem that there is an upward trend over time. Secondly, I marked each mine and stockpile manually, which means my results are prone to error. I did my very best to stick to the five characteristics I outlined in the methods section, but the quality of some images made identifying some of the features very difficult which could have resulted in a slight under or overcount of active mines for the 2018 dataset. Additionally, I give myself a six-month window outside the year to account for variability in satellite imagery availability. This again could have caused a slight miscount of active mining sites the year I represented them. For the land reclamation totals, I again manually traced polygons to calculate the total areas, so error is to be expected.

In my fieldwork at the sand mines, I was very short on time and resources, and thus my visit to the region was incomplete. I only had the chance to visit eight mining sites, only four of which were operating. I also only spoke to people that I naturally ran into so my sample for information is not representative of the region as a whole.

### 6.5 Directions for Further Research

Sand mining is an extremely broad topic touching many fields, as well as both human and physical geography. This thesis allowed me to draw on three diverse fields of research as well as many topics from both geomorphology and social science. More research should be done on the Malaysian sand mining industry. The industry is an excellent example of an understudied and very environmentally and economically impactful sector for the nation, with ties to urbanization as well as ecological decline. Just from my own research, the racial composition and relationships of the industry could be more interesting to explore. The geomorphological impacts of mass sand extraction from the river system are undeniable, but a more quantitative approach to assess the impact on the system would help to establish to what extent sand removal is changing the system. Given more time and knowledge of GIS analysis techniques, a proper quantitative analysis of the sand mine location data I collected could provide more definitive results in the trend of sand mine locations in the Muda River system. Finally, a full-fledged analysis of the sand supply chain would help to assess how much sand is leaving the Muda Basin, and to where exactly the sand is being used.

### 6.6 Conclusion

Sand is the most extracted substance that humans take from the earth, except for water (*UNEP*, 2019). Given the size and scope of this industry, it receives very little academic attention. In this thesis, I attempted to expand the knowledge of this pervasive anthropogenic process by focusing on one fluvial system heavily impacted by sand mining, the Muda River. By taking a narrow approach, the widespread damage that over-exploiting sand resources has taken on a river system becomes much more apparent. There have been few attempts to map sand mining on such a compact scale before, and though my conclusions are not unexpected, they nonetheless help to fill a gap in the sand mining literature. By focusing on one system, it is possible to better understand the socio-economic situation of the region as well. Sand mining is completed nearly everywhere in the world, but the methods of extraction differ greatly from region to region (Padmalal & Maya, 2014). By visiting the region, it is easier to understand and empathize with those mining sand. Yes, sand mining is a destructive industry, but given the demand by rapid urbanization and marginal other economic prospects, it is possible to understand and contextualize the harm with the benefit provided to the local people.

Land reclamation is the other anthropogenic process I tracked in this thesis, focusing on three areas on the west coast of Malaysia: Forest City, Melaka Gateway, and Penang Island. Forest City is a struggling Chinese real estate venture that pre-covid expanded rapidly, though afterward is now struggling. The Melaka Gateway was a domestic project with foreign ties designed to spur regional growth and has been the fastest-reclaiming project surveyed. Penang Island is home to two major projects, the Andaman Islands, and Gurney Wharf, though the area has seen many land reclamation projects over the past 30 years. Collectively, these three areas have added 31 square kilometers of developable land, most of which has been created in the past 15 years. Land creation of this magnitude greatly impacts both local cities and economies, but natural processes of erosion and environmental health as well. Much of this development can be understood to be speculative as well, meaning that these areas are reclaimed without a clear future development goal.

By understanding these two processes as closely related, and in some cases interlinked such as with Penang and the Muda River, the story of sand is better understood. Sand from the Muda River is a key driver of development in Penang, enabling that city's rapid expansion both vertically and horizontally. Sand is also an overlooked resource, as its extraction has both environmental, hydrological, economic, and morphological impacts on the river system. The ever-upstream search for fresh sand deposits is a sign that sand stocks are being depleted in the system. The straightening of the river decreases the river's natural ability to disperse floodwaters. The economic influx of sand money has provided countless livelihoods for those who call the Muda Basin home. The sand has allowed Malaysia to become a middle-income country. All are true and represent tradeoffs of material extraction and deserve further study. I believe geographers are best equipped to study trends such as this because we are trained in both physical and human-focused sciences.

## References

Aliu, I. R., Akoteyon, I. S., & Soladoye, O. (2022). Sustaining urbanization while undermining sustainability: The socio-environmental characterization of coastal sand mining in Lagos Nigeria. *GeoJournal*, *87*(6), 5265–5285. https://doi.org/10.1007/s10708-021-10563-7

Anthony, E. J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., & Nguyen, V. L. (2015). Linking rapid erosion of the Mekong River delta to human activities. *Scientific Reports*, *5*(1), 14745. https://doi.org/10.1038/srep14745

Ashraf et al. (2011). Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia. *Scientific Research and Essays*, *6*(6), 1216–1231.

Avery, E., & Moser, S. (2023). Urban speculation for survival: Adaptations and negotiations in Forest City, Malaysia. *Environment and Planning C: Politics and Space*, *41*(2), 221–239. https://doi.org/10.1177/23996544221121797

Beech, H. (2018, August 20). 'We Cannot Afford This': Malaysia Pushes Back Against China's Vision. *New York Times*. https://www.nytimes.com/2018/08/20/world/asia/china-malaysia.html

Bendixen, M., Best, J., Hackney, C., & Iversen, L. L. (2019). Time is running out for sand. *Nature*, *571*(7763), 29–31. https://doi.org/10.1038/d41586-019-02042-4

Bendixen, M., Noorbhai, N., Zhou, J., Iversen, L. L., & Huang, K. (2023). Drivers and effects of construction-sand mining in Sub-Saharan Africa. *The Extractive Industries and Society*, *16*, 101364. https://doi.org/10.1016/j.exis.2023.101364

Bujang, J. S., Zakaria, M. H., & Short, F. T. (2016). Seagrass in Malaysia: Issues and Challenges Ahead. In C. M. Finlayson, G. R. Milton, R. C. Prentice, & N. C. Davidson (Eds.), *The Wetland Book* (pp. 1–9). Springer Netherlands. https://doi.org/10.1007/978-94-007-6173-5_268-1

Bunnell, T. (2004). *Malaysia, Modernity and the Multimedia Super Corridor* (0 ed.). Routledge. https://doi.org/10.4324/9780203647363

Cai, Z., Liu, Q., & Cao, S. (2020). Real estate supports rapid development of China's urbanization. *Land Use Policy*, *95*, 104582. https://doi.org/10.1016/j.landusepol.2020.104582

Chapman, D. M. (1984). The edge of the sea. In *Beaches and coastal Geology*. Springer US.

Chee, S. Y., Othman, A. G., Sim, Y. K., Mat Adam, A. N., & Firth, L. B. (2017). Land reclamation and artificial islands: Walking the tightrope between development and conservation. *Global Ecology and Conservation*, *12*, 80–95. https://doi.org/10.1016/j.gecco.2017.08.005

Cipriani, L. (2022). Land of sand: Reclaiming the sea, landscapes and lives in Malacca, Malaysia. *City*, *26*(5–6), 888–910. Scopus. https://doi.org/10.1080/13604813.2022.2126168

*Comprehensive management plan of Muda river basin*. (1995). JICA. https://openjicareport.jica.go.jp/pdf/11253218_01.pdf

Connolly, C. (2023). The spatialities of extended infrastructure landscapes: The case of Malaysia's Melaka Gateway project. *Landscape Research*, *48*(2), 212–223. https://doi.org/10.1080/01426397.2021.2021161

Cooke, S. J., Piczak, M. L., Nyboer, E. A., Michalski, F., Bennett, A., Koning, A. A., Hughes, K. A., Chen, Y., Wu, J., Cowx, I. G., Koehnken, L., Raghavan, R., Pompeu, P. S., Phang, S., Valbo-Jørgensen, J., Bendixen, M., Torres, A., Getahun, A., Kondolf, G. M., … Taylor, W. W. (2023). Managing exploitation of freshwater species and aggregates to protect and restore freshwater biodiversity. *Environmental Reviews*, er-2022-0118.

https://doi.org/10.1139/er-2022-0118

Dissanayake, C. B., & Rupasinghe, M. S. (1996). Environmental impact of mining, erosion and sedimentation in Sri Lanka. *International Journal of Environmental Studies*, *51*(1), 35–50. https://doi.org/10.1080/00207239608711069

Gavriletea, M. (2017). Environmental Impacts of Sand Exploitation. Analysis of Sand Market. *Sustainability*, *9*(7), 1118. https://doi.org/10.3390/su9071118

Ghani, A. Ab., Ali, R., Zakaria, N. A., Hasan, Z. A., Chang, C. K., & Ahamad, M. S. S. (2010). A temporal change study of the Muda River system over 22 years. *International Journal of River Basin Management*, *8*(1), 25–37. https://doi.org/10.1080/15715121003715040

Goldman, M. (2011). Speculative Urbanism and the Making of the Next World City: Speculative urbanism in Bangalore. *International Journal of Urban and Regional Research*, *35*(3), 555–581. https://doi.org/10.1111/j.1468-2427.2010.01001.x

Hackney, C. R., Darby, S. E., Parsons, D. R., Leyland, J., Best, J. L., Aalto, R., Nicholas, A. P., & Houseago, R. C. (2020). River bank instability from unsustainable sand mining in the lower Mekong River. *Nature Sustainability*, *3*(3), 217–225. https://doi.org/10.1038/s41893-019-0455-3

Hackney, C. R., Vasilopoulos, G., Heng, S., Darbari, V., Walker, S., & Parsons, D. R. (2021). Sand mining far outpaces natural supply in a large alluvial river. *Earth Surface Dynamics*, *9*(5), 1323–1334. https://doi.org/10.5194/esurf-9-1323-2021

Harun, M. A., Ab Ghani, A., Mohammadpour, R., & Chan, N. W. (2020). Stable channel analysis with sediment transport for rivers in Malaysia: A case study of the Muda, Kurau, and Langat rivers. *International Journal of Sediment Research*, *35*(5), 455–466. https://doi.org/10.1016/j.ijsrc.2020.03.008

Harvey, D. A. (2005). *A brief history of neoliberalism*. Oxford University Press.

Hoeksema, R. J. (2007). Three stages in the history of land reclamation in the Netherlands. *Irrigation and Drainage*, *56*(S1), S113–S126. https://doi.org/10.1002/ird.340

Hutchinson, F. E., & Yean, T. S. (2021). THE BRI IN MALAYSIA'S PORT SECTOR: DRIVERS OF SUCCESS AND FAILURE. *Asian Affairs*, *52*(3), 688–721. https://doi.org/10.1080/03068374.2021.1957305

*IMF Datamapper: Real GDP Growth*. (2023). Imf.Org. https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/SEQ

Jordan, C., Tiede, J., Lojek, O., Visscher, J., Apel, H., Nguyen, H. Q., Quang, C. N. X., & Schlurmann, T. (2019). Sand mining in the Mekong Delta revisited—Current scales of local sediment deficits. *Scientific Reports*, *9*(1), 17823. https://doi.org/10.1038/s41598-019-53804-z

Lamb, V., Marschke, M., & Rigg, J. (2019). Trading Sand, Undermining Lives: Omitted Livelihoods in the Global Trade in Sand. *Annals of the American Association of Geographers*, *109*(5), 1511–1528. https://doi.org/10.1080/24694452.2018.1541401

Mark, M. E. (2021). *The Governance of Global Sand Mining* [University of Ottawa]. http://hdl.handle.net/10012/16946

Mngeni, A., Musampa, C. M., & Nakin, M. D. (2016). The Effects of Sand Mining on Rural Communtities. In *Sustainable Development and Planning VIII* (pp. 443–453). https://books.google.ca/books?id=d_oeDgAAQBAJ&lpg=PA443&ots=MJZNVml94-&dq=human%20sand%20mining&lr&pg=PA443#v=onepage&q=human%20sand%20mining&f=false

Moser, S. (2018). Forest city, Malaysia, and Chinese expansionism. *Urban Geography*, *39*(6), 935–943. https://doi.org/10.1080/02723638.2017.1405691

Mutemeri, N., Walker, J. Z., Coulson, N., & Watson, I. (2016). Capacity building for self-regulation of the Artisanal and Small-Scale Mining (ASM) sector: A policy paradigm shift aligned with development outcomes and a pro-poor approach. *The Extractive Industries and Society*, *3*(3), 653–658. https://doi.org/10.1016/j.exis.2016.05.002

Ng, K.-K. (2020, December 21). Property Development in Malaysia amid COVID-19 Pandemic: A Matter of Capital Growth or Housing Affordability? *London School of Economics*. https://blogs.lse.ac.uk/seac/2020/12/21/property-development-in-malaysia-amid-covid-19-pandemic-a-matter-of-capital-growth-or-housing-affordability/

Padmalal, D., & Maya, K. (2014). Sand Mining: The World Scenario. In D. Padmalal & K. Maya, *Sand Mining* (pp. 57–80). Springer Netherlands. https://doi.org/10.1007/978-94-017-9144-1_5

Pascale, P. (2014). Sand, rarer than one thinks. *Environmental Development*, *11*, 208–218. https://doi.org/10.1016/j.envdev.2014.04.001

Pow, C. P. (2014). License to travel: Policy assemblage and the 'Singapore model.' *City*, *18*(3), 287–306. https://doi.org/10.1080/13604813.2014.908515

Runeckles, H., Hackney, C. R., Le, H., Thi Thu Ha, H., Bui, L., Do, N., & Large, A. (2023). "Local people want to keep their sand": Variations in community perceptions and everyday resistance to sand mining across the Red River, Vietnam. *The Extractive Industries and Society*, *15*, 101336. https://doi.org/10.1016/j.exis.2023.101336

*River Sand Mining Guidelines*. (2020). Department of Irrigation and Drainage Malaysia.

Sengupta, D., Choi, Y. R., Tian, B., Brown, S., Meadows, M., Hackney, C. R., Banerjee, A., Li, Y., Chen, R., & Zhou, Y. (2023). Mapping 21st Century Global Coastal Land

Reclamation. *Earth's Future*, *11*(2), e2022EF002927. https://doi.org/10.1029/2022EF002927

Shepard, W. (2020, January 31). Inside The Belt And Road's Premier White Elephant: Melaka Gateway. Forbes. https://www.forbes.com/sites/wadeshepard/2020/01/31/inside-the-belt-and-roads-premier-white-elephant-melaka-gateway/?sh=1c188520266e

Sridhar, M. K. C., Ana, G. R. E. E., & Laniyan, T. A. (2019). Impact of Sand Mining and Sea Reclamation on the Environment and Socioeconomic Activities of Ikate and Ilubirin Coastal Low Income Communities in Lagos Metropolis, Southwestern Nigeria. *Journal of Geoscience and Environment Protection*, *07*(02), 190–205. https://doi.org/10.4236/gep.2019.72013

Tambajong, H., Laiyan, D., Kontu, F., Tjilen, A. P., Djalal, N., Pasaribu, Y. P., Buyang, Y., & Marlissa, I. (2018). Role of Indigenous People Institutions in Efforts to Reduce Mining Actions of C-Class Quarry Sand. *Proceedings of the 1st International Conference on Social Sciences (ICSS 2018)*. Proceedings of the 1st International Conference on Social Sciences (ICSS 2018), Bali, Indonesia. https://doi.org/10.2991/icss-18.2018.293

Tan, M. L. (2019). Assessment of TRMM product for precipitation extreme measurement over the Muda River Basin, Malaysia. *HydroResearch*, *2*, 69–75. https://doi.org/10.1016/j.hydres.2019.11.004

Tellman, B., Sullivan, J. A., Kuhn, C., Kettner, A. J., Doyle, C. S., Brakenridge, G. R., Erickson, T. A., & Slayback, D. A. (2021). Satellite imaging reveals increased proportion of population exposed to floods. *Nature*, *596*(7870), 80–86. https://doi.org/10.1038/s41586-021-03695-w

Torres, A., Brandt, J., Lear, K., & Liu, J. (2017). A looming tragedy of the sand commons.

*Science*, *357*(6355), 970–971. https://doi.org/10.1126/science.aao0503

United Nations Environment Programme (2019). *Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources*. https://wedocs.unep.org/20.500.11822/28163.

Yee, A. T. K., Ang, W. F., Teo, S., Liew, S. C., & Tan, H. T. W. (2010). The Present Extent Of Mangrove Forests In Singapore. *Nature in Singapore*, *3*, 139–145.

Zhong, X., Deetman, S., Tukker, A., & Behrens, P. (2022). Increasing material efficiencies of buildings to address the global sand crisis. *Nature Sustainability*, *5*(5), 389–392. https://doi.org/10.1038/s41893-022-00857-0

## APPENDIX:

**Data Sources:**

For the GIS analysis, I used satellite images available in Google Earth, as they are the highest resolution images available that I had access to at no personal cost. For the land reclamation analysis, images from Forest City were: 12/30/1985, 12/30/2000, 12/30/2005, and 12/20/2010 Copernicus/Landsat, 2/20 and 2/25/2015 Maxar, 1/25 and 3/3/2020 Maxar, and 6/4/2023 Airbus. For the Melaka area, the dates were 12/30/1985, 12/30/1990, 12/30/1995, 12/30/2000 Copernicus/Landsat, 1/30/2005 Maxar, 12/30/2010 Copernicus/Landsat, 1/17/2015 CNES/Airbus, 9/16/2020 Maxar, and 7/3/2023 Airbus. For Penang Island, again 1985, 1990, 1995, and 2000 are Copernicus/Landsat images, 1/22/2005 Maxar, 2/19/2010 Maxar, 1/23/2015 Maxar, 1/21/2000 Maxar, and 12/12/2023 Airbus. For the sand mine analysis, images used were: 11/11/2008 Maxar, 1/16/2018 Maxar, 11/29/2022 Maxar, 12/7/2017 Maxar, 4/8/2018 Maxar, 8/26/2022 Maxar, 1/20/2013 CNES/Airbus, 1/23/2014 CNES/Airbus, 1/29/2014 CNES/Airbus, 1/20/2013 CNES/Airbus, 7/8/2017 CNES/Airbus, and 9/15/2023 Airbus. The Copernicus/Landsat images have a resolution of 30m or 15m depending on the year. The Maxar satellite has a resolution of 30-31cm, CNES/Airbus is 30 cm as well. Some images, notably the 12/7/2017 Maxar image, were very cloudy so intuition by looking at the nearest images was used to ascertain if sand mining was occurring in locations obstructed by clouds. All dates are in (MM/DD/YYYY) format.

All images and maps created by the author unless otherwise noted.