Evolution process of land reclamation in Macao and its impact on economy and ecology

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ABSTRACT

The city of Macao has always been a typical example of reclamation. With more room for variety of land uses especially for public facilities, it brings opportunities for city development. However, some unexpected impacts have been discovered regarding land reclamation in Macao. This article analysed reasons and evolution process of Macao's land reclamation, and discussed their impacts on city development. QGIS software is used to analyse the Landsat satellite images data, and classification maps and land cover change maps are obtained. Through analysing these images, this study can clearly recognize the land change situation in Macao. The results show that the area of land reclaimed from the sea in Macao in the past 30 years is very huge, but the area covered by vegetation has also decreased. The land reclaimed from the sea has been used to build casinos and transport facilities, these lands give an explosive development to Macao's economy in the past three decades. Meanwhile, the positive development of Macao's population and economy has also promoted the further implementation of land reclamation. Both economic as well as ecological negative impacts, however, have been discovered. One of the hugest ecological impacts are destruction of vegetation and worsening water quality, and high cost is the major economic impact.

Keywords: *economy, ecology, Macao, reclamation*

1. INTRODUCTION

Land reclamation refers to using particular methods to gain landmass for a specific usage; the most common utilization of land reclamation is to claim land near coastal area, generally by pouring earth, sand, and other sediment onto the seafloor until it accumulates above sea level [1]. Coastal land reclamation is rather pervasive nowadays, some of the most significant reclamation projects took place in Hong Kong (in order to fulfill its niche as international trading post and to host more people since 1840s, after it was ceded to Great Britain), Netherlands (to reclaim their territory from rising sea level and to improve their soil quality) [2], Singapore (for a similar reason Hong Kong faced) [3], and Macao. It is clear that expanding land area is an effective and straightforward method to develop the economy of coastal cities in the case of large population.

Compared with other cities, Macao is a representative land reclamation city in China. First and foremost, Macao is the most densely populated area; in the year 2021, its population density has reached 21,055 people per sq kilometer, which is 2,000 people per sq kilometer above Monaco, the second place [4]. Take the St. Anthony Parish of Macao Peninsula as an example, streets there are narrow and crowded, and most main streets are two-lane two-way roads. Residential apartments are usually around 30 stories tall, with small entrances on the sides of streets and parking lots integrated into several stories above ground, for there is hardly any space below ground. It is obvious that the city is in need of more housing project and public facilities, such as hospitals, police stations, to certainly lead to a higher living standard for local residents. According to that, land reclamation is crucial to resolve the city's civil problems.

Furthermore, large infrastructures, such as airports and docks, always need large flat area to be built on. Macao is a city built on islands; from Cologne to Macao Peninsula, there was no area for an airport initially. Therefore, the entire terminal and the runway of Macao International Airport are built on reclaimed land. In addition, the Hong Kong-Zhuhai-Macao Bridge's

construction involved land reclamation, too. An artificial island was erected on the eastern coast of Macao Peninsula to serve as a port into Macao area. Furthermore, two other artificial islands were built in the middle part of the bridge, serving as rest stops and entrance to the undersea tunnel due to the bridge's extensive length. In addition, According to Chinese government's schedule, large cities near Pearl River Delta, Hong Kong, Macao, Shenzhen, Guangzhou, for example, will be soon integrated into "Pearl River Delta Megacity Region", the world's busiest city agglomeration. In order to be more competitive, Macao need to develop its industry [1], for the fact that Macao has a weak industrial foundation. In this way, more factories and good outlets must be built, which will take more land from Macao's already limited space. To counteract the drawback, again, Macao has to take a bet on land reclamation.

Besides of Macao's demand for land reclamation, its geologic environment supports it too. According to geology record, Macao never had any earthquake above magnitude 5—a great condition for land reclamation to take part in. Secondly, the lithosphere below Macao is mainly consisted of pyrogenetic rock, which is easy to crumble, adding another advantage for the city's adoption of land reclamation [5]. Besides its demand and natural suitability for land reclamation, isn't there other consequences? In the following sessions, this article concentrated on the evolution process and negative impacts of land reclamation in Macao.

2. HISTORY OF LAND RECLAMATION IN MACAO

2.1.Macao's Geographic Information

Considering Macao's land reclamation, it is crucial to present Macao's geology data. The city of Macao is initially consisted of two islands, Taipa Island and Coloane Island, and the Macao Peninsula, with total area about 11 square kilometers (Figure 1).

Macao Peninsula is the place where the historical part of the city is located. Since the 15th century, the Portuguese merchants and colonizers had taken place as their own trading port. As for today, the Macao Peninsula is the most populated area, with residential area spreading over the central and northern area, while luxury hotels and several campuses dominate the southern area.

Taipa and Coloane Islands are located in the south of the Peninsula. The two islands are converted into a single landmass by reclaiming land in the area between the two islands. From the map, we can see that some area on this landmass is covered in vegetation, as shown by their greenish color, these areas are generally where the two original islands are located. The interconnecting part is now called the Cotai zone, and it serves as a recreational zone featuring shopping malls, casinos, and the best hotels in the city.

The Taipa Island in the north is a small but multipurpose area, with high-end housing in the west part and industrial in the east, the Macao's dock and airport is also located in the east side of Taipa. The Coloane Island in the south, on the other hand, is more like a natural reserve, where urbanization progress is restricted; Coloane also acts as a representative of Mazu culture—a prominent religion in Southern China based on nautical practices. Except from forementioned main landmasses, reclaimed artificial islands also take a large percentage of Macao's land area: mainly the Macao Int'l Airport, the Bridge terminal and a newly constructed land on the east coast of the Peninsula.

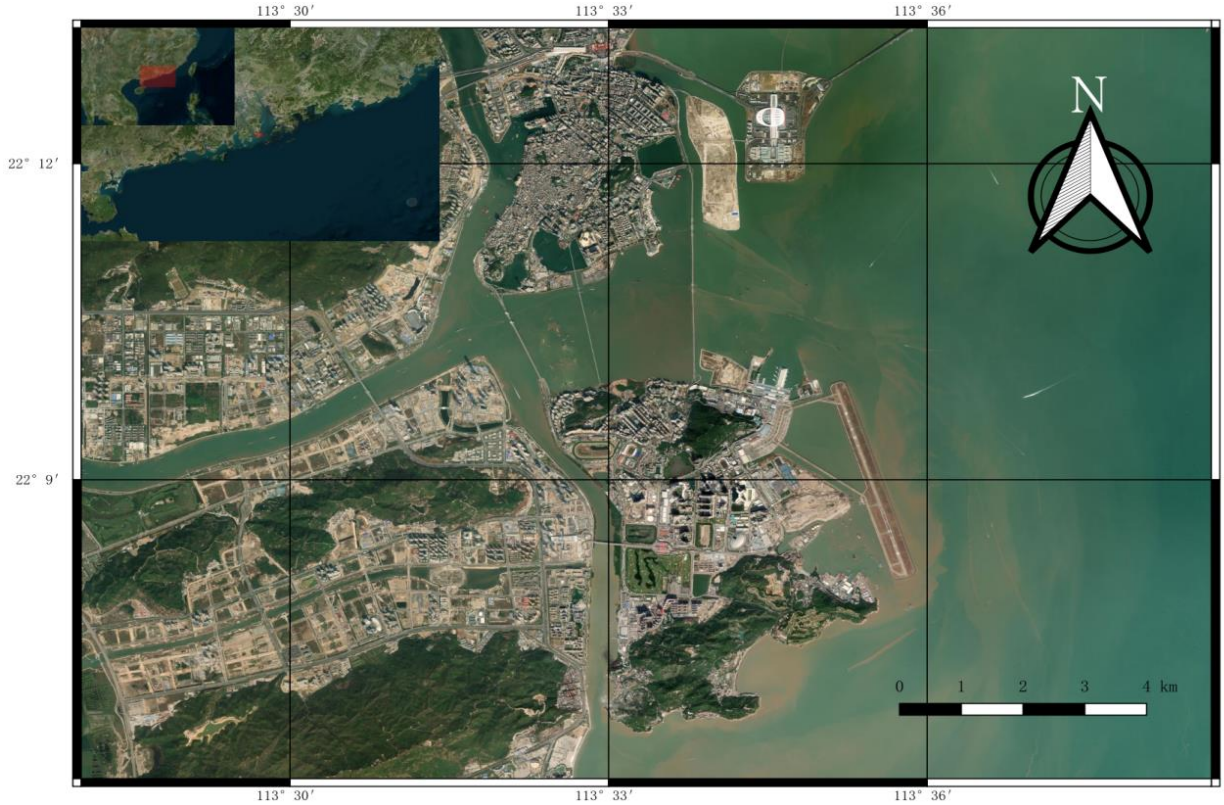


Figure 1. Satellite Map of Macao S. A. R., satellite data retrieved from Google Map

2.2.Development of Land Reclamation in Macao

The first stage of Macao's land reclamation started in Mid-19th century in Porto Interior shallow water area, but in a relatively minor scale. Due to the fact that Chinese Empire's government opened several "treaty ports" in Southern China, Macao's position as an international commercial center is vandalized. This results in comparably stagged economic growth in Macao for several decades since 1840s; this results in a lack of funding in land reclamation, consequently slowed down the process. Until in 1887, when dilapidated Chinese Empire Government acknowledges the sovereignty of Portugal in Macao, its position as a colony started to develop.

The Second period began in early 20th century, which marks the first practice Macao did to reclaim land systematically. [3] It took part at northwestern, northeastern, and southeastern Macao Peninsula, these areas are now main residential area serving multipurpose uses. Macao's population grew rapidly in that period, mainly from immigrants from Chinese Mainland, where was political instable; this provided the island city a source of cheap labor, which supported the land reclamation project to go smoothly and continuously. This is further strengthened when Japanese took over Shanghai and Hong Kong in the late 30s and early 40s, promoting even more immigration to Macao. This prosperity ceased after the end of the WWII, due to several political complications (tense relationship with PR China, including but not limited to reasons like Chinese civil war, China's socialism ideology, "Culture Revolution", etc., and 1974 revolution in its mother country Portugal), which almost completely ceased the development of Macao, [3] to the extent that there's little if any record for the expansion in land area between 1949 and 1984, according to the Macao government. This political and economic crisis slowly resolved since 1979 when China and Portugal established diplomatic relationship—this leads to the third stage of land reclamation in Macao.

Funded by both Chinese and Portuguese enterprises and financial groups, the third stage of land reclamation concentrated on Taipa and Coloane Island. The strait between two islands was filled with reclaimed matter during this period from two sides of the Taipa and Coloane Continuity Road, which was built in the 60s. [6] The whole reclaimed area, nearly 6 square kilometers, was named Cotai Reclaimed zone. Furthermore, the Macao International airport was also built in this period. There was also several subordinate land reclamation program in Macao Peninsula, especially those in Porto Exterior and southern Freguesia da Sé, which formed Nam Van Lake, the largest artificial lake in Macao.

After Macao reunited with China in 1999, the land reclamation maintained at a steady speed with government fund from China. In this era, land reclamation focused more on public infrastructure and practicability instead of Macao's tourism and gambling. A large island on the eastern coast of Macao Peninsula

was designed to be a housing project estimated to provide housing for 57,000 people, including several parks and culture center for public recreation. A seaside boulevard area in the southernmost part of the peninsula was reclaimed to be utilized as an administrative center and also a bus station.

Several smaller islands are estimated to be constructed north of Taipa; these islands, in particular, will be the first set of housing zones designed as low-carbon pilot areas, in order to show the dedication for the city to engage in sustainable development; in addition, there will also be parks near the ocean, where citizens can enjoy leisure activity. [7]

3. DATA AND METHODS

In particular, the land reclamation between 1989 and 2021 consisted mainly of large-scale projects, which establishes Macao's economic and civil position in the 21st century, which arouses many researchers' interest. Besides, the launch and popularization of several series of satellites in the 80s, the Landsat series for example, provides researchers a comprehensive view of the change. As a result, this study chooses the period between 1989 and 2021 as the main focus of study.

This study needs satellite images of the Macao region from the same period to clarify the change between Macao's land mass and city area between 1989 and 2021. We can obtain the corresponding satellite data from https://earthexplorer.usgs.gov/. Due to the different service operating hours of the Landsat series of satellites, Landsat5 satellites were launched in 1984 and decommissioned in June 2013, and Landsat8 was successfully launched in February 2013 and is still in service. As a result, this paper adopts the data from the Landsat5 satellite for 1989 to 2013 and the data of Landsat8 to study the changes from 2013 to 2021.

3.1.Band Combination Maps

The QGIS software was used for image analysis after downloading the data. Because through the use of Band Combination, our team can better analyze the environmental characteristics of the city by using two SWIR bands and red bands. Therefore, for Landsat5 our team used RGB753, for Landsat8, this study used RGB764. Then our study acquired images of Macao region in 1989, 1995, 1999, 2005, 2010 and 2021 (Figure 2). People can know about that the urban development changes in Macao from these six pictures more clearly.

Table 1. Landsat 4-5 Thematic Mapper (TM)

Landsat 4-5	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120(30)
Band 7	2.08-2.35	30

Table 2. Landsat 8-9 Operational Land Image (OLI) band Thermal Infrared Sensor (TIRS)

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2- Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 -Red	0.64-0.67	30
Band 5-Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.112.29	30
Band 8-Panchromatic	0.50-0.68	15
Band 9 -Cirrus	1.36-1.68	30
Band 10-Thermal Infrared (TIRS)1	10.6-11.19	100
Band 11-Thermal Infrared (TIRS)2	11.50-12.51	100

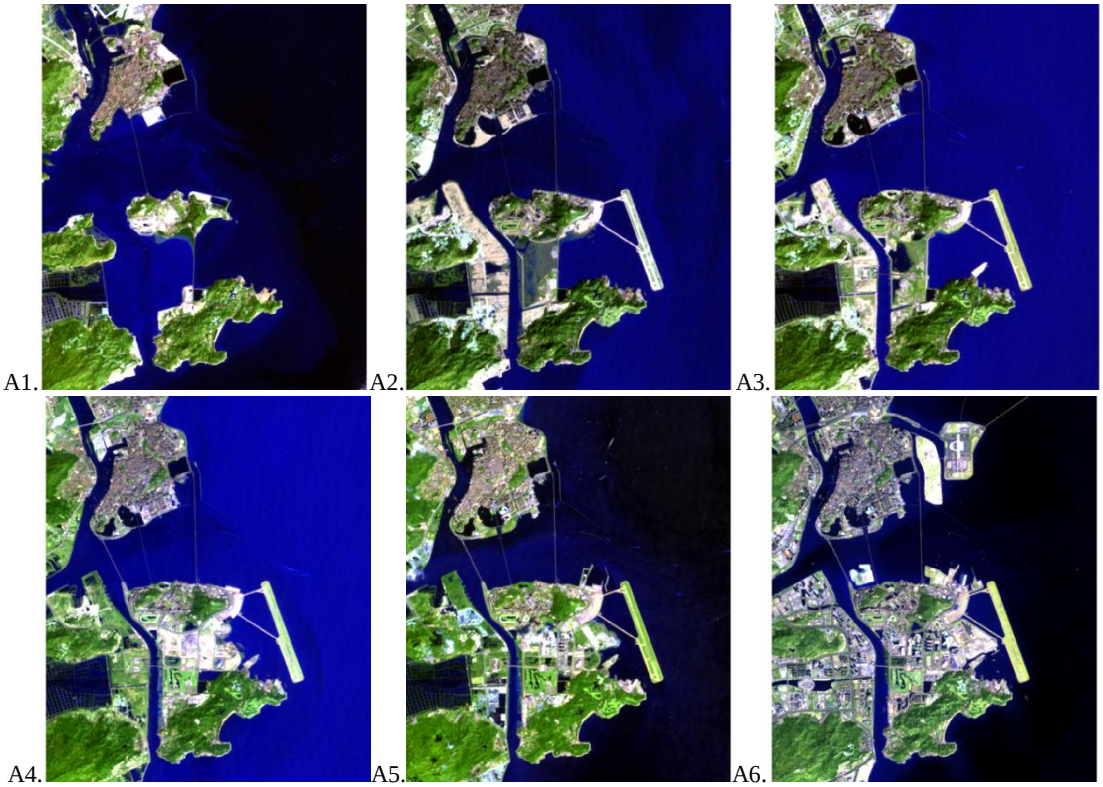
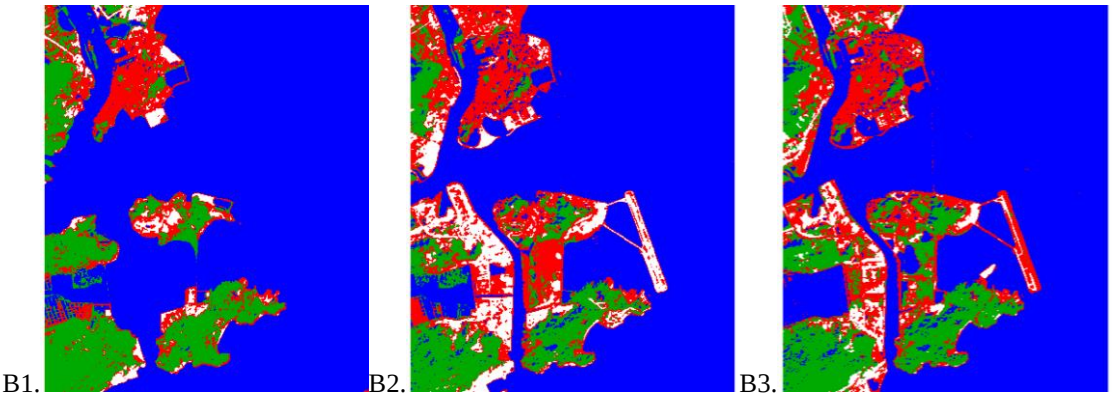


Figure 2. Band Combination Maps in (A1) 1989 (A2) 1995 (A3) 1999 (A4) 2005 (A5) 2010 (A6) 2021

3.2.Classification Maps

This study uses the Semi-Automatic Classification Plugin in QGIS to classify the map elements to recognize such a change more clearly. Image classification is one of the most important tasks in image processing and analysis, and it is used to analyze the situation of land use and land cover classes. First, this study gets the original Landsat satellite images, which are not enough to analyze. As a result, this study needs to do more processing on them. Then this study uses the QGIS to analyze the image classification, and different colors represent different substances. By analyzing the colors in these images, and then it is known that red areas are buildings, blue areas are waters, green areas are vegetation, and white areas are uncultivated land. Finally, six Classification Maps can be obtained (Figure 3). The changes in land, vegetation, and oceans in Macao over the years can be seen from these six maps. There is a significant increase in the red area, which means that the land area of Macao is getting larger. However, the green part is decreasing distinctly, especially since 2010, which shows that the vegetation area in Macao is decreasing. Therefore, Macao needs to pay attention to the protection of vegetation.



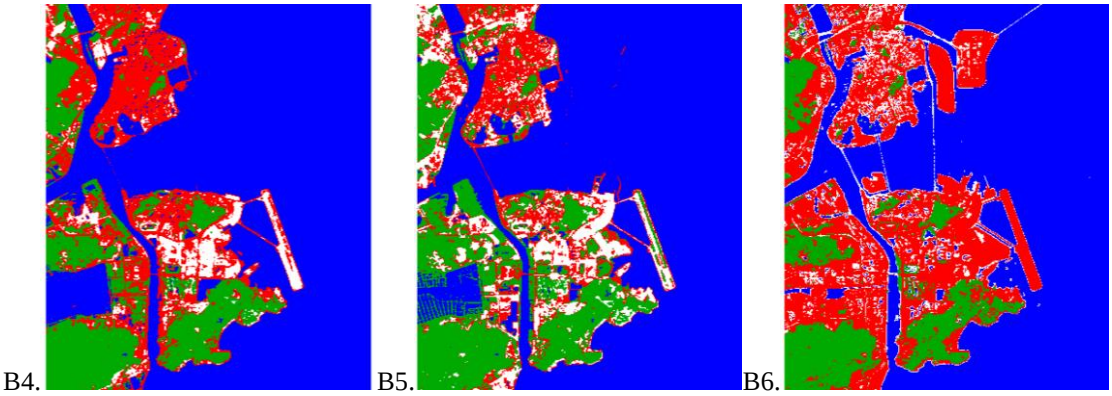


Figure 3. Classification Maps in (B1) 1989 (B2) 1995 (B3) 1999 (B4) 2005 (B5) 2010 (B6) 2021

3.3.Land cover change maps

To make the changes between years clearer, our team used the Land cover change function in the Semi-Automatic Classification Plugin to analyze the changes in 1989-1995, 1995-1999, 1999-2005, 2005-2010, 2010-2021, and 1989-2021. Then these six Land cover change maps are obtained (Figure 4). The orange part in the picture represents the area where water becomes a building. The Red part represents the area where water becomes uncultivated land. In this way, the development of Macao's land reclamation in different years can be recovered.

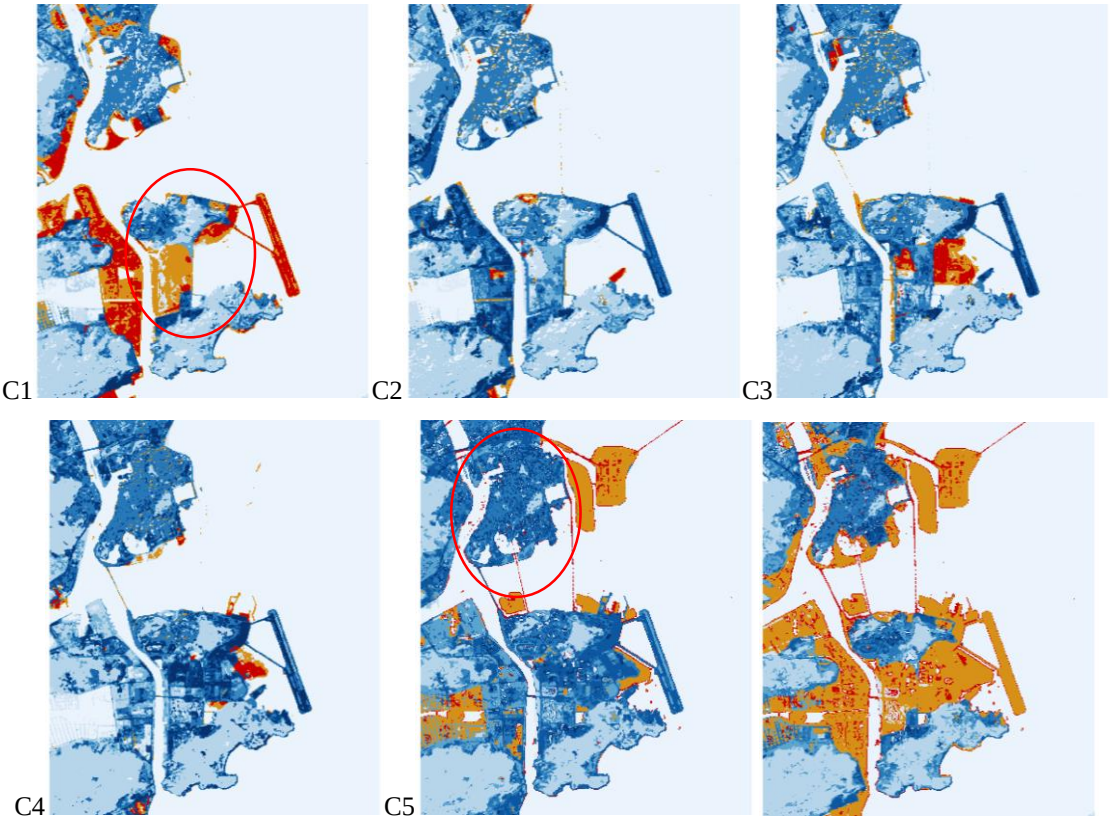


Figure 4. Land cover change Maps in (C1) 1989-1994 (C2) 1994-1999 (C3) 1999-2005

(C4) 2005-2010 (C5) 2010-2021; (C6) 1989-2021

4. EVOLUTION OF LAND RECLAMATION BETWEEN 1989 AND 2021

At the end of the 1980s, new land reclamation was mainly associated with large civil infrastructure projects, including the new Macao international airport and the new ferry terminal to other main ports in the Pearl River region. The latest large-scale reclamation in Macao has mainly been conducted in the Cotai region since the 1990s [8].

It created a 5.2 km^2 piece of newly reclaimed land

from the sea between Taipa and Coloane Islands in order to provide Macao with a new gambling and tourism area. Numerous largescale urban developments have been conducted in the Cotai reclamation area, such as the Macao University of Science and Technology, Macao East Asian Games Dome, Cotai Strip, Galaxy World Resort. The Cotai Strip is one of the largest casino and tourism projects in the world.

Cotai was the result of a major land reclamation project which joined the two islands of Coloane and Taipa, and is part of the Macao government's continuous efforts to expand the region's territory. The reclaimed land in Cotai is to be mainly used for casino developments. Moreover, the Cotai Strip is an important emerging tourism area in Macao, integrating hotel, exhibition, leisure, performance and entertainment elements. The project is under construction and will have about 20 large hotels with a total of about 60,000 rooms, more than a dozen large casinos, a number of large shopping malls, several exhibition venues, and a number of large performance venues. The total investment is expected to reach us $12-15 billion and will take about 7 to 10 years to develop 8 sites in 3 phases.

Macao International Airport was built entirely by land reclamation, which has greatly promoted the development of Macao's economy and tourism. However, if Macao International Airport wants to increase its throughput, it will have to continue to reclaim land from the sea to increase its area. In addition, from 1989-1995, reclamation was mainly carried out in the western area of Cotai, but a lot of it was not being exploited. Later, the Venetian Macao, Studio City Macao, the Plaza Macao, Galaxy Macao were built on this area.

From 1999-2005, the land reclamation is mainly in the eastern part of Cotai. Later casinos such as The City of Dreams, MGM Cotai, Wynn Palace, and The Londoner Macao were built on this area. In addition, The Macao University of Science and Technology and the Macao East Asian Games Dome were also built in this area, and the Macao East Asian Games Dome is one of the major venues of the 2005 East Asian Games and also hosted some events for the 2007 Asian Indoor Games. Therefore, the land reclaimed from the sea has not only developed Macao's economy, but also contributed greatly to its education and infrastructure.

From 2010 to 2021, The main reclamation project is the construction of the Hong Kong-Zhuhai-Macao Bridge (The red circle in the Figure 4-C5).

The reclamation part of the project started on December 15, 2009, which is the earliest construction project of the Hong Kong-Zhuhai-Macao Bridge project and the largest reclamation area of the artificial island project of the Bridge. The completion of the bridge brings more tourists to Macao and strengthen the connection between Macao and neighboring cities such as Hong Kong, Zhuhai and Shenzhen, which has a great effect on Macao's transportation and economy.

Therefore, Macao's land reclamation can solve many of Macao's transportation and housing problems. As one of the most densely populated areas in the world, land reclamation is an important strategy for Macao's urban development. Figure 4-C6 shows that the area in Macao reclaimed from the sea in recent 30 years is very huge, which is almost the same as the entire land area of Macao 30 years ago. Although marine environment, even the whole natural environment in Macao has harmed by this measure to a certain extent, the explosive development of Macao's economy in the past three decades cannot be ignored [5]. At the same time, the positive development of Macao's population and economy has also promoted the further implementation of land reclamation. Therefore, land reclamation in Macao is always intertwined with population growth and economic development. Today, Macao has undergone significant changes, advancing towards a diversified economic system.

In the future, Macao will become a beautiful city with developed industry and commerce, booming tourism and prosperous financial industry.

5. IMPACTS OF LAND RECLAMATION IN MACAO

5.1.Positive Impact

It can be discover that land reclamation is crucial for Macao’s development as it brings huge benefit, it could potentially improve the city’s competitiveness in the future among competition with neighboring cities, it can improve the living standard for the residents of Macao as it provides more space from reclaimed land to facilitate their needs (e.g. Infrastructure and public facilities such as the 19000 housing units, Hong Kong-Zhuhai-Macao bridge, sub-aquatic tunnel which provides convenient transportation, gardens-leisure options, administrative judicial offices and municipal public service). The economic development over the years can also be linked closely to land reclamation projects, the tourism industry, partially involves the gambling and entertainment [9], is the biggest employer in the city and accounting 54.18% of its GDP [10].

5.2.Negative Impacts

There are many inevitable negative impacts of those land reclamation projects, some are ecological impacts while others are human or economic impacts.

5.2.1.Ecological Impacts

The ecological impacts of land reclamation can be

mainly classified into animal, plant and environmental aspects. However, those impacts are often intertwined with one another.

For example, death of mangrove forest is one of the consequences of land reclamation. One example is that the mangrove forest at the shoal next to the Casas – Museu da Taipa was the biggest mangrove forest in all of Macao with area of 57.2 hectares, and it has withered in 1998 due to the blockage caused by land reclamation that separated the wetland from the ocean that caused worsened water quality. The death of those mangrove forest can have a great impact on the local ecology because of its importance in the ecosystem.

It can be observed from the comparison between 1989 and 1999. that the vegetation coverage around Museu da Taipa the over one decade has decreased (Figure 5). The decreased plant coverage involves not only mangrove forest but also other types of vegetation.

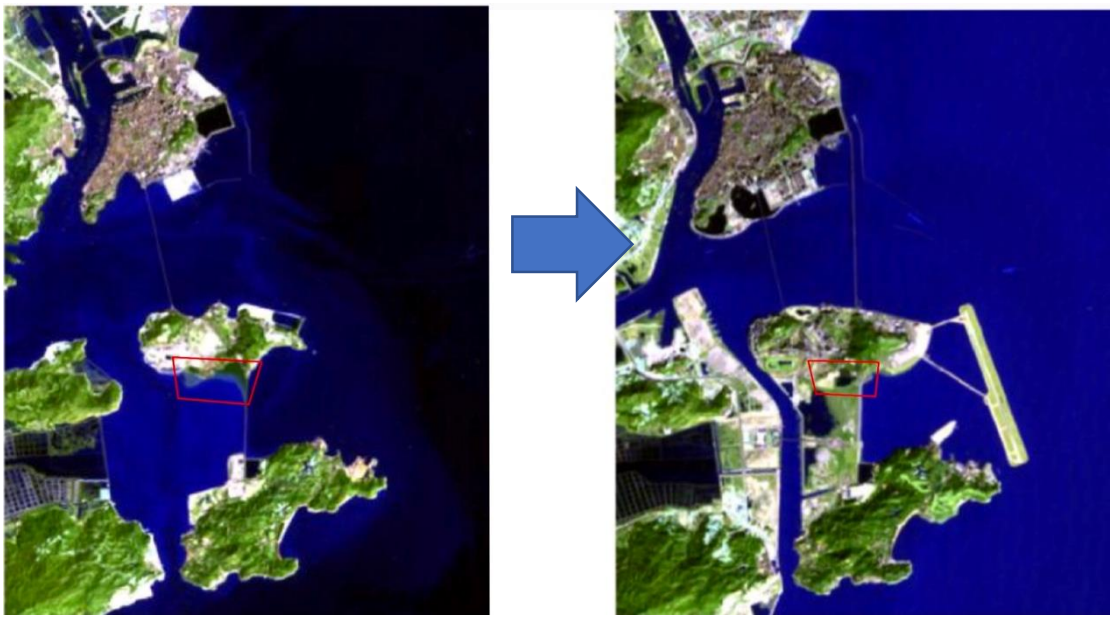


Figure 5. Brief location of mangrove forest next to Museu da Taipa from 1989 (left) to 1999 (right)

As mentioned above, the wildlife would be disturbed by Land Reclamation, because the land reclamation projects occupy the habitat of marine life, cause worsened water quality, and changes in hydrological characteristics, thereby severely change their surviving conditions for organisms, making the environment hard to adapt. This often have negative effects on the spawning and migration of aquatic life. As a result, the both population and diversity of the fauna (e.g., Migratory birds and fish) dropped drastically.

The removal and destruction of wetlands are due to deteriorating environment and changing topography and contour of the shoreline by removing and reclaiming sediments by the coastal regions. Wetlands can serve as protection to a coastal region such as Macao from storm surge intrusion. But the disappearance of coastal wetlands will affect the flood drainage of the city and potentially make Macao more vulnerable to such natural disasters, especially with the risk of rising water level in the upcoming years [11].

It does not only stabilize coastlines and prevent erosion by holds the sediments with its roots, it also filters pollutants such as nitrates and provide refuge for a variety of wildlife. Thus, land reclamation will lead to further water and air pollution, change in the coastline, potential decrease of tourism in specific region and damaged ecosystem along with decreasing biodiversity.

Macao has suffered from saline water intrusion (salt-tides) and it can be partially attributed to the land reclamation projects [12]. The dredging activities - both legal and illegal, growing demand for water and over-extraction of other resources are the main cause of saline water intrusion. The sediments dredged from the pearl river basin were used in the land reclamation projects. In recent decades, the Hongwan channel's width has shrank 100 – 200m upstream and 300 – 400m downstream. Because of the decreasing width in certain waterway due to land reclamation, the sediment deposition and water retention has led to deterioration of water quality and intensified the saline water intrusion.

5.2.2.Economic Impacts

Land reclamation has negative impacts on business activities of some industries such as fishing and commercial shipping with the fishing industry being likely hit the hardest. Its high cost can also be seen as one disadvantage.

An industry affected is the shipping industry, since the original wide channel is now partially occupied by

reclaimed land, leaving a narrower channel and less space for large cargo ships to pass through [13]. However, according the Director of Maritime Affair of Macao there the impact would not be severe as the current plan would leave sufficient width (50% of the original channel) for ships to pass through, only the pace may be slower.

The commercial fishing industry in Macao was hit hard as a result of land reclamation projects, since many of the fish species with decreasing population are targets of commercial fishing. So, the number of fish captured would drop sharply and may cause economic losses for companies and individuals who works in fishery industry [13]. Since the 1990s, the commercial fishing business has been declining, that the number of fishing vessels has dropped sharply from more than 800 in 1980s to approximately 100 in 1990s[14]. A lot of the former employees of the commercial fishing industry has now changed their career to work in other industries [15]. Other factors such as worsened water quality that are results of land reclamation also contributed to the shrinking of Macao's fishing industry.

Moreover, the cost of reclaiming land is considered to be extremely high, cost of reclaiming 350 hectares of land can be over to 10billion RMB ($1.54 billion), this may be a financial burden for the government as it may take up a considerable proportion of the fiscal budget and forcing the government to cut spending on other subjects which may benefit the people and societies in other ways.

6. CONCLUSION

This article introduces the reasons, evolution process and impact of land reclamation in Macao.

6.1.Evolution Process

Macao land reclamation in recent 30 years is very huge, which is almost the same as the entire land area of Macao 30 years ago. From 1989 to 1995, reclamation was mainly carried out in the western area of Cotai, the Macao international airport was also built during this time. From 1995-2005, the land reclamation is mainly in the eastern part of Cotai. Today, Cotai is one of the most prosperous parts of Macao, there are almost all of Macao's casinos. After 2010, the Hong Kong-Zhuhai-Macao Bridge is the main reclamation project, it was put into operation on October 24,2018. However, there are still some problems; such as the area of vegetation in Macao has also decreased significantly, and the marine environment is also deteriorating. Although the marine environment, and even Macao's entire natural environment has suffered a certain extent, the great contribution to explosive development of Macao's economy cannot be ignored.

6.2.Impacts

It can be discovered that land reclamation has many positive impacts on the city of Macao as it provides more space for development opportunities in key industries such as tourism, facilitate the public's need and more importantly make the city more competitive among its neighboring cities.

However, land reclamation also brings some negative impacts, especially ecology and economy. It could narrow channels which could make it harder for ships to pass through, and change surviving conditions for organisms could disturb the marine life. It also reduces the population and diversity of fish, further brings negative impacts to the fishing, and reduces habitats for many migratory birds, and changes topography which may impact the coastal wetland system. It also indirectly affects the flood drainage and defense against storm surge intrusion, worsens water quality, and lead to death of mangrove forests in this region. Furthermore, the cost of reclaiming land is extremely high, cost of reclaiming 350 hectares of land can be over to 10billion RMB ($1.54 billion), this may be a financial burden for the government.

6.3.Future Expectations

For the future urban planning of Macao, the city should aim to develop diversely, holistically and sustainably in order to remain competitive among its neighboring cities. Both environmental (ecological) and economic impact should be taken in to consideration and careful evaluation to balance the affects, where negative and unwanted impacts on the environment as well as the society should be at minimal level. Use of the reclaimed land should be for the public use, such as infrastructure to facilitate the resident's need instead of high-end real estate which cannot benefit the majority. Similar consideration should also be taken for other regions that wish to follow the example of Macao. Measure of protection should be taken for the environment as well as employment in certain industries.

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