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APPLICATION OF GIS TO EVALUATE THE SITUATION OF SALTWATER INTRUSION ON AGRICULTURAL PRODUCTION IN THE MEKONG DELTA

In the dry season of 2019-2020

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Abstract

The Mekong Delta has played an important role in the food production and socio-economic development in Vietnam. However, the region has witnessed different natural disasters intensified by climate change, which has caused heavy damages to livelihoods and agricultural production. Drought and saltwater intrusion are reoccurring events in the delta, and the dry season of 2019-2020 recorded a new milestone in salinity, along with a long drought and saline intrusion period at the beginning of 2020.

The objectives of the thesis were to provide an overview of drought and saltwater intrusion in Vietnam's Mekong Delta in relation with the livelihood of residents, create a saltwater intrusion map of the delta for the dry season of 2019-2020 based on a geographic information system (GIS) interpolation method, assess the effects on the agricultural production and identify major causes to emphasize the urgency of proposing and implementing corrective and mitigation measures to minimize the damage and loss.

The thesis presents a literature review to provide general information on the drought and saltwater intrusion in the Mekong Delta. Kriging interpolation algorithm was used, based on the pre-measured salinity points, to create a saltwater intrusion zoning map for the delta. The study showed that in the dry season of 2019-2020, the Mekong Delta had an exceptional drought and saltwater intrusion event. According to the map, salinity decreased gradually from the coast into the mainland with the greatest concentration in the southernmost area. Approximately half of the agricultural production area and the population in the delta were forecast to be at risk of saltwater intrusion. This research method proved beneficial, in terms of simplicity and accuracy. Therefore, it was possible to apply it to studies related to saltwater intrusion in other areas. As for the complicated phenomenon of climate change, the assessment of salinity intrusion at higher specificity and accuracy needed aggregating many factors. It was considered to propose and implement corrective and mitigation measures, both constructional and non-constructional, to minimize the damage and loss from saltwater intrusion.

Keywords

drought, saltwater intrusion, agriculture, interpolation algorithm, mapping

CONTENTS

1 INTRODUCTION

The territory of Vietnam is located in an area prone to various natural disasters. Storms, floods, and droughts often occur every year, which makes it necessary to take advanced and proactive measures. One of the most important issues in environmental protection in Vietnam is the ecological and environmental imbalance (Vietnam Ministry of Education and Training [MOET], 2014). Prolonged dryness and drought, saline intrusion in the dry season occur in many places. The dry season is usually more severe in southern Vietnam, and the dry period lasts up to 4-5 months in the southern plain. Every year, drought and saltwater intrusion cause damage to tens of thousands of hectares of crops and agricultural production areas, greatly affecting people's life (Vietnam Ministry of Natural Resources and Environment [MONRE], 2020). Many localities have organized good prevention measures to minimize the damage caused by salinity and drought.

The delta terrain region plays the most important role in the food production and socio-economic development in Vietnam. The Mekong River Delta is the largest river delta in Vietnam. The middle and lower parts of the Mekong River flowing through the Vietnamese territory have created a large and fertile land for the delta. The Mekong Delta consists of 13 provinces and cities (directly under the Central Government) with an area of over 40 thousand square kilometers, accounting for 12% of the national area and a population of more than 17.8 million people, accounting for 18.8% of the total population nationwide (2018) (General Statistics Office of Vietnam [GSO], 2020).

The Mekong Delta has a dry season from December to April. The lower part of the delta is constantly affected by tides and waves. The water level in the estuaries rises and falls quickly, and the salinity gradually penetrates the soil (MOET, 2014). Currently, Vietnam is witnessing the most severe drought in the Mekong Delta in the last 5 years. Despite being known as an area with a rich river system, the Southwest region is suffering from dryness due to a lack of fresh water and saline intrusion, causing loss in production, making thousands of households lack of fresh water for daily life, and leaving thousands of hectares of rice, vegetable, and fruit crops withering and dying. It is estimated that up to 180,000 households are suffering from freshwater in-adequacy, significantly affecting people's lives. (Ministry of Foreign Affairs, 2020.)

According to To Van Truong, former Director of Southern Institute of Water Resources Planning (2020), water scarcity, drought and salinization in the Mekong Delta often occur in years with extreme climate and weather conditions. An analysis of the meteorological data from 1975 to present shows that the severity of climate-weather extremes in Vietnam tends to increase markedly. Therefore, the extent of water scarcity, drought and salinization in the Mekong Delta is also increasing in terms of time, space, intensity, frequency and the associated economic and environmental damage caused by them.

In recent decades, the upper Mekong countries have planned to increase the use of water for agricultural production as well as for hydroelectricity and other economic activities. The inevitable result is a decrease in water flow from upstream and water shortage in the annual dry season (Tran et al., 2012). The weather situation has been extremely complicated due to climate change through the manifestations of abnormal weather phenomena such as rising temperatures, drought and especially saline intrusions in coastal areas, thereby seriously affecting cultivation and agricultural activities. Climate change narrows the availability of agricultural land, especially in coastal cultivation lowland areas in the Mekong Delta due to sea level rise (Nguyen et al., 2017).

A new historic milestone in salinity in this area established with a long drought and saline intrusion period at the beginning of 2020 (Vietnam Academy of Agriculture Sciences, 2020). During the dry season 2019-2020, there was a wide range of news, forecasts, and statistical reports on drought and saline intrusion in the Mekong Delta to update the situation and inform people. However, this monitoring has not been systematic and consistent and it had become necessary to review the progress of this natural disaster situation and make appropriate assessments. A new research was needed for systemizing the information provided from various sources on drought and salinization in the Mekong Delta in the dry season of 2020 with a focus on the impacts of the disaster on food production – the key driver of the region's economic development, proposing solutions and emphasizing lessons after the 2016 drought.

For the above reasons, this study was conducted with aims to

a) Provide an overview of drought and saltwater intrusion in Vietnam's Mekong Delta in relation with the livelihood of residents.
b) Create a saltwater intrusion map of Mekong Delta (dry season 12/2019-04/2020) based on geographic information system (GIS) interpolation method, assessing the effects on the agricultural production.
c) Identify the major causes, emphasize the urgency of proposing and implementing corrective and mitigation measures to minimize the damage and loss.

2 THEORETICAL BACKGROUND

The Mekong Delta has witnessed different natural disasters intensified by climate change, which has caused heavy damages to livelihoods and agricultural production. Drought and saltwater intrusion are two major disasters that frequently occur in the region with high intensity. Saltwater intrusion has a direct relation to the severity of drought.

2.1 Drought

Drought is a phenomenon of serious water shortage which lasts for a long time due to insufficient rainfall and depletion of water sources (Disaster Management Policy and Technology Center, 2015). Drought occurs in almost all climatic regions with characteristics that vary greatly from region to region (Nguyen et al., 2007). There are different definitions of drought, including drought is the result of a shortage of natural rainfall over a long period, usually a season or longer (Wilhite, 2000) and drought is a long enough period of unusually dry weather due to lack of rain and causing a serious water imbalance; or a lack of rainfall over a long period, causing water shortages for many activities (Tran et al., 2008).

Generally, drought is a shortage of rain for a relatively long time. Drought is a temporary anomaly, different from the aridity in areas with little rainfall and is a regular feature of the climate (Nguyen et al., 2007).

2.1.1 Causes of drought

Drought can be caused when there is little or no rain or by way of water imbalance, reduced moisture in soil and air, lack of irrigation and human impact. There are many causes of drought which can be divided into the following two main categories. Objectively, natural factors such as abnormal climate (precipitation, evaporation rate), depletion of water sources (surface water, groundwater), unfavorable terrain and soil condition cause water shortages, failing to meet human needs in terms of living, agricultural production and socio-economic and environmental activities. Subjectively, although drought is a natural phenomenon, it is also affected by human activities (Tran et al., 2008). People have contributed to exacerbating droughts. For example, indiscriminate deforestation causes loss of groundwater resources, leading to water depletion. Similarly, unsuitable planting and development of crops that need much water in dry areas (such as rice) causes depletion of water resources. Moreover, the awareness of people concerning the sustainable use of resources is limited, and policy systems are still lacking in synchronization.

There are many factors that affect drought, from precipitation and evaporation to water sources (surface water and groundwater). Other influencing factors are topography (i.e., slope), as well as the ability of soil and forests to retain water (Dao et al., 2003).

2.1.2 Adverse impacts of drought

Drought has a great impact on the environment, economy, politics, society and human health (Nguyen, 2011). Drought affects the environment by destroying wildlife, plants and animals, reducing the quality of air and water or increasing the risk of forest fires and soil erosion. The impact of drought on socio-economy includes the reduction of crop productivity and cultivated area, leading to an increase in agricultural production costs and a reduction in agricultural income, furthermore, increasing food prices and reducing the total value of livestock products. Drought also creates many difficulties for the operation of hydropower plants. Additionally, drought is also a contributing factor in the breakout of poverty, disease and even war due to water conflicts.

2.2 Saltwater Intrusion

Saltwater intrusion is the phenomenon of saline water with a salinity of 4 ‰ penetrating deep into the soil due to high tides, sea level rise or fresh water exhaustion (Disaster Management Policy and Technology Center, 2015). The saltwater intrusion is caused, for example, by the depletion of river water making the sea water flow along the rivers and canals in the dry season. This natural phenomenon occurs every year, therefore, can be predicted in advance. Coastal areas are also at risk of saline intrusion due to osmosis.

2.2.1 Causes of saltwater intrusion

According to the Department of Agriculture and Rural Development of Ben Tre Province (2010), the main cause leading to saline water intrusion in the dry season months is the low amount of precipitation and water flowing from the upstream. When the water level is low, combined with the northeast monsoon, trade wind elements and high tides cause deeper saline intrusion and higher concentration of salt. In hot weather, the evaporation rate is high so the amount of fresh water is naturally reduced. Saltwater intrusion is a debatable problem for the local authorities, and attempts have been made to resolve this issue in the context of climate change, for example with reference to rising sea levels, increased temperatures, and excessive groundwater extraction to satisfy the water demand for development. These reasons are escalating the risk of salinity intrusion.

According to the analysis center of the National Agency for Science and Technology Information (Nasati), there are various factors affecting saltwater intrusion. In nature, the interface between fresh water and salt water is rarely stable. The process of supplying water or exploiting groundwater leads to the fact that the interface between fresh water and saline water changes from one location to another. In addition, climate change can profoundly impact the hydrological cycle through alteration in precipitation patterns, evapotranspiration and soil moisture. Other meteorological factors, for example, wind, temperature and precipitation, as well as terrain characteristics and especially human activities, such as changing land use purposes and increasing demand for fresh water in the dry season also influence the severity of saltwater intrusion.

2.2.2 Adverse impacts of saltwater intrusion

Saltwater intrusion directly affects people's daily life as well as cultivation and production. The lack of fresh water in the dry season causes many difficulties and much damage. Agricultural activities dependent on the fresh water sources are affected, especially rice cultivation. High water salinity seriously affects a plant's growth and development process, reducing productivity and even causing its death. Furthermore, saltwater intrusion increases the salinity level in the soil and affects the quality of underground water.

3 RESEARCH BACKGROUND

The Mekong Delta is a region with favorable geographical position, rich and diverse soil, climate, water and animal resources alongside with a good availability of workers for goods production. Those are important conditions to build the Mekong River Delta (the Southwestern region) into a dynamic economic region of the country.

3.1 Geographical location, territorial limit

The Mekong Delta is located to the west of the Southeast region of Vietnam, bordering Cambodia to the north, the Gulf of Thailand to the southwest and the East Sea to the southeast.

Figure 1. Administrative map of the Mekong Delta (Center of Survey and Mapping Data, 2019)

The geographical significance of the Mekong Delta includes the adjacency to the Southeast region which is a thriving economic region and a market that consumes many of the goods of the Mekong Delta (agricultural and fishery products) and employs a number of people from the delta. Sharing a long border and convenient connections (both road and waterway traffic) with Cambodia, the Mekong Delta has the advantage to develop cooperative relationships with the Mekong sub-region countries. Bordered by the East Sea with a long coastline and large sea areas with abundant shrimp and fish resources and many tidal flats, mangroves and estuaries suitable for fishing and aquaculture, the delta also offers opportunities for exchange with different domestic and foreign areas by sea. Located in the southernmost part of the country, near the equator, the climate of the Mekong Delta is solely characterized by the subequatorial conditions, with abundant moist and heat sources as well as favorable weather for agricultural production. The Mekong Delta has beneficial conditions to develop tropical agriculture throughout the year, especially rice paddies and tropical fruit crops. Therefore, it has advantageous foundation for an economic development on the mainland as well as expansion of sea trade and cooperation with countries in the Mekong sub-region.

3.2 Natural conditions and resources

The Mekong Delta is a part of the Mekong River Basin. The main soil groups in the Mekong Delta include acid sulfate soil, saline soil and fresh alluvial soil, which is the most fertile and suitable for crops, distributed in strips along the Tien and Hau rivers (MOET, 2014).

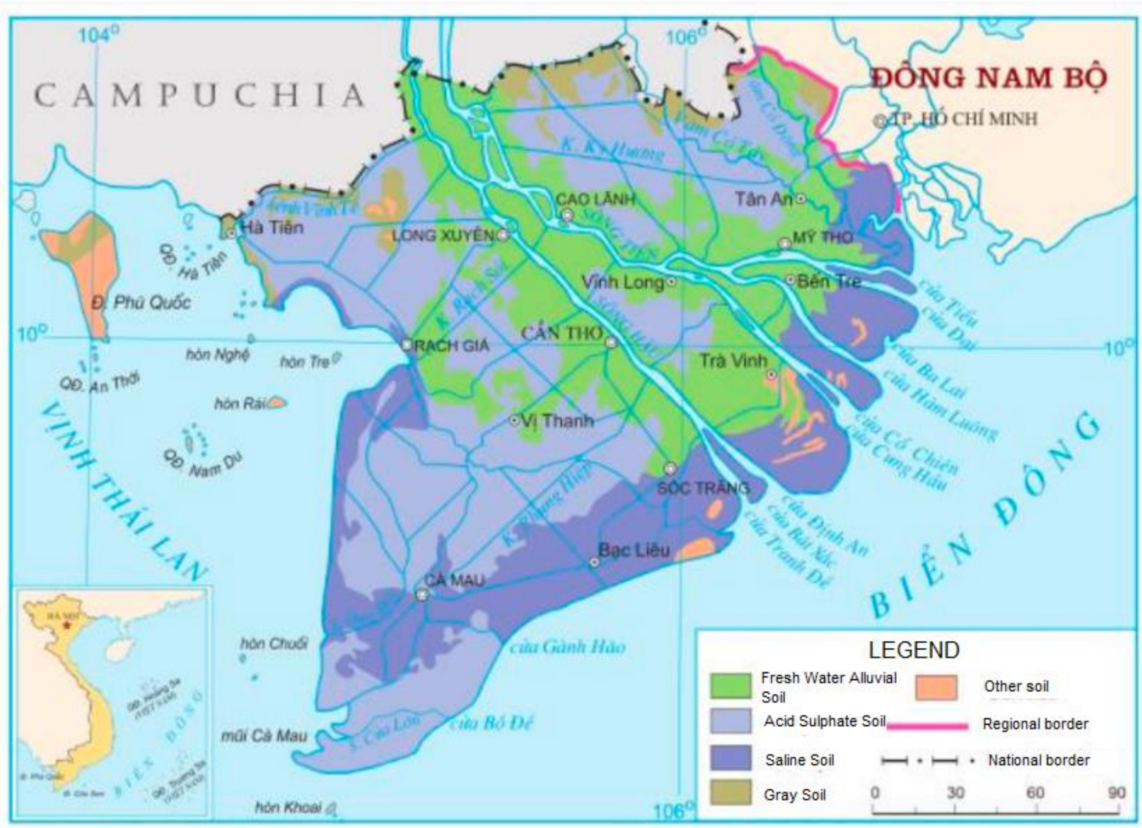


Figure 2. Distribution of main soil types in the Mekong Delta (MOET, 2014)

With a relatively large area, low and flat terrain, hot and humid subequatorial climate and terrestrial and aquatic biodiversity, the Mekong Delta has favorable natural conditions for the development of agricultural production. The main natural resources in the region include soil and forest, with a total area of approximately 4 million ha (1.2 million ha of alluvial fresh soil, 2.5 million ha of acid sulfate soil and saline soil) and coastal and Ca Mau peninsula mangroves. In terms of climate, it is hot and humid, with abundant rainfall. Additionally, the Mekong River brings great resources and a rich and dense canal system, mixing with saline water and brackish water in estuaries and coastal areas. Having a diverse range of sea life and vast fishing grounds, many islands and archipelagos, the Mekong Delta is appropriate for seafood exploitation. (MOET, 2014)

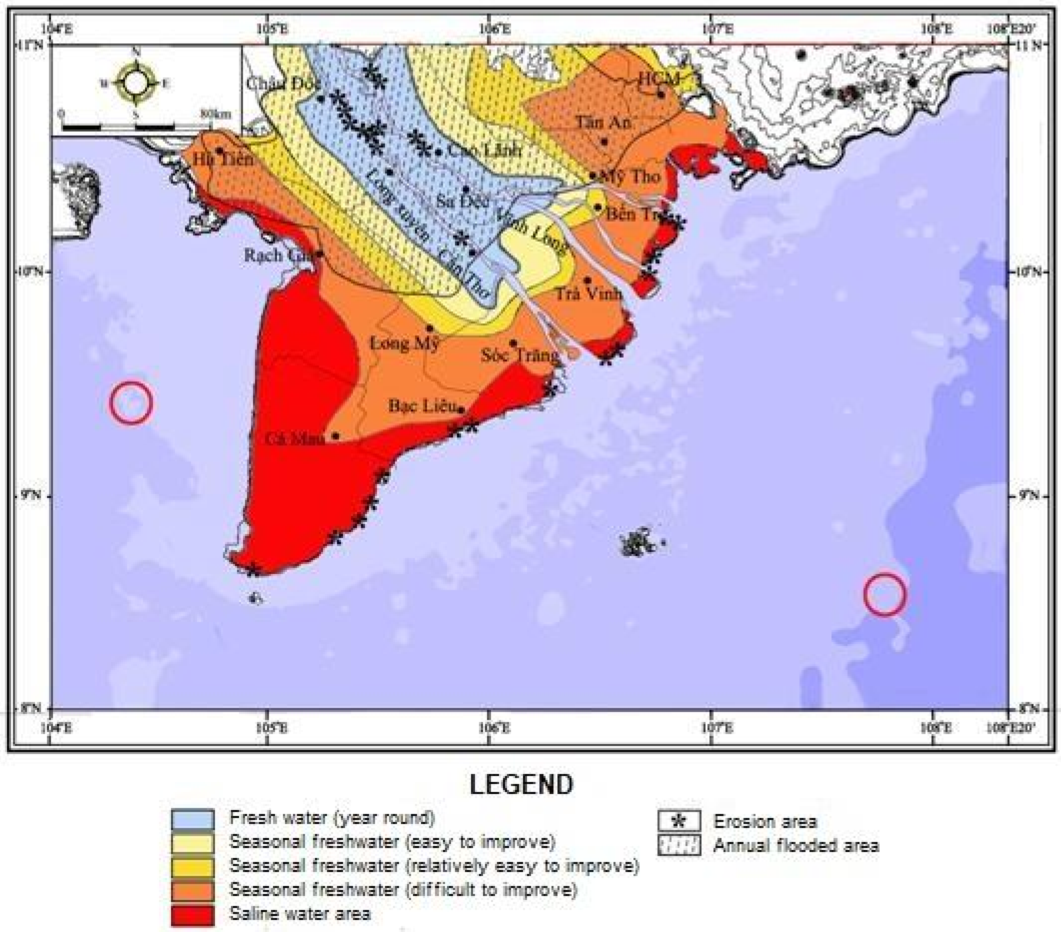


Figure 3. Zoning map of water types in the Mekong Delta (Phung, 2011)

The Mekong Delta is being greatly invested for projects on flood drainage, acid sulfate and saline soils improvement, supplying fresh water for production and daily consumption in the dry season. The current strategy is to actively adapt with the Mekong floods while exploiting the economic advantages brought by the flood itself.

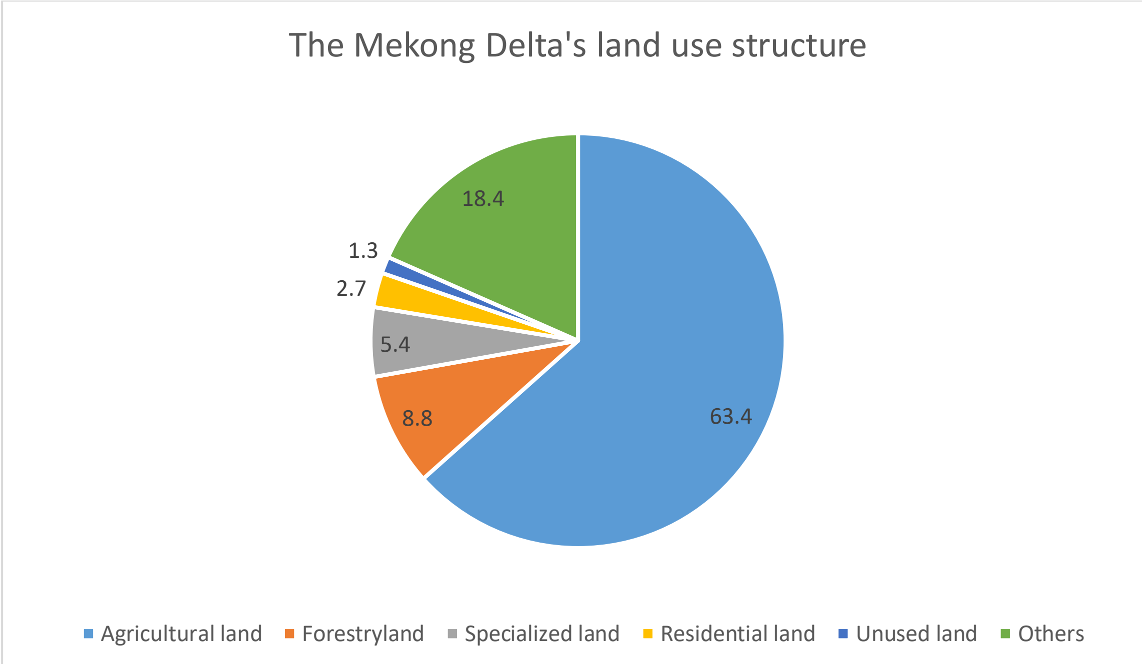


Figure 4. Land use structure of the Mekong Delta in 2005 (%)

However, the natural conditions also cause many difficulties and challenges for the agricultural production and livelihood in the Mekong Delta. For instance, acid sulfate and saline soil occupy a large area (approximately 60% of the delta's area), requiring sufficient investments and time for renovation. Having long dry seasons (from December to April), the region faces a shortage of fresh water for production and daily consumption, along with saline intrusion problems. Moreover, annual floods occur on a large scale by the banks of Mekong River during the rainy season. Environmental quality in many areas is being degraded, especially the water resources in rivers and canals.

3.3 Residential and social characteristics

With a population of 17.8 million people (in 2018) (GSO, 2020), the Mekong River Delta is one of the most populous regions in Vietnam, ranked in the second place after the Red River Delta.

Table 1. Some criteria for population and social development in the Mekong Delta and the whole country (in 2018) (GSO, 2020)

Criteria	Unit	Mekong Delta	Vietnam
Population density	Person/sq. Km	436	286

The rate of natural population increase	%	0,38	1,06
The rate of poor households	%	5,2	5,8
Adult literacy rate	%	92,8	94,8
Average life expectancy	Year	74,9	73,5
Rate of urban population	%	24,7	35,7

Discovered more than three hundred years ago, today the Mekong Delta has become a rich agricultural region. People in the Mekong Delta have long tradition and vast experience in agriculture production.

3.4 Economic development situation

The Mekong Delta is a focal area for food production and the leading agricultural export region of the country. Also, the industry and service sectors are beginning to develop.

The Mekong Delta is the largest rice-growing region in Vietnam. Rice is mainly grown in Kien Giang, An Giang, Long An, Dong Thap, Soc Trang and Tien Giang provinces. The average food amount per capita in the whole region reached 1066.3 kg, which is 2.3 times higher than the national average (in 2002) (MOET, 2014). As a result, the Mekong River Delta has become the main rice exporting region in Vietnam. Many localities are increasing the cultivation area for sugarcane and vegetables crops.

Table 2. Rice area and production in the Mekong Delta and the whole country in 2018 (GSO, 2020)

Criteria	**Mekong Delta**	**Vietnam**
Area (thousand hectares)	4107,4	7570,4
Production (million tons)	24,4	43,9

The Mekong Delta is the largest fruit tree growing area in the country with a variety of tropical fruits, such as mango, coconut, orange and grapefruit. Of the total national fishery output, the Mekong Delta accounts for more than 50%, with the highest production occuring in Kien Giang, Ca Mau and An Giang provinces. Aquaculture, especially for shrimp and fish exports, is thriving. Forestry is also important, especially for coastal and Ca Mau peninsula mangrove afforestation. The localities are taking active measures to prevent and prepare for forest fires, protecting biodiversity and ecological environment of the mangrove forests. (MOET, 2014)

Compared with agriculture, the proportion of industrial production is still low, accounting for approximately 20% of the region's GDP (in 2002) (MOET, 2014). Food processing mainly includes rice milling, frozen seafood processing, canned vegetables and fruit processing and sugar production. Export products, such as rice, frozen seafood and fruits are distributed in different provinces and cities. Agricultural engineering is being developed in some areas (MOET, 2014).

The service sector in the Mekong Delta also relies on import and export. The main export products are rice (accounting for 80% of the country's exported rice, in 2000 according to MOET), frozen seafood and fruits. The delta is being highly invested to improve the quality and economic efficiency of the service sector.

4 THE SITUATION OF DROUGHT AND SALTWATER INTRUSION IN THE MEKONG DELTA

Drought and saltwater intrusion have continuously occurred in the Mekong Delta over years with different intensity and damages. In 2016, the region faced a historical drought and saltwater intrusion, however, in the dry season of 2019-2020, a more severe saltwater intrusion event has been recorded with an exceptionally low water level in the Mekong River.

4.1 The situation of drought and saltwater intrusion until the Southern Vietnam Drought in 2016

In Vietnam, drought occurs in different regions with varying levels and periods of time, causing enormous economic and social losses, especially in agricultural production. Over the past 40 years, there have been many severe droughts in the Central and Southern regions, most notably in 1993, 1998 and 2016. (Asian Disaster Preparedness Center)

The Mekong Delta has approximately 2.9 million hectares of agricultural land, of which rice farming area accounts for approximately 2 million hectares. Agricultural production (rice and fruit trees) and fishery are the two major activities in the region's economy. Endowed with favorable natural conditions and weather, crops can be grown almost year-round. However, the primary feature of the Mekong River's flood is that it often begins late and ends early, hence, droughts are inevitable. Furthermore, the main flow of the Mekong River during the dry season is usually low. Seawater penetrates deeply into the land, sometimes up to 40-50 km, causing difficulties to grow crops.

Droughts that had occurred in years have affected 4,000 – 230,000 hectares of agricultural land and completely destroyed 1,000 – 390,000 hectares of farmland. The drought in the winter-spring and summer-autumn crop in 1998 left 1,100,000 people in water shortages. Therefore, it is necessary to have a comprehensive and effective hydro-meteorological management plan for the Mekong Delta, one of the key economic regions of the country, to protect and maintain its resources (Asian Disaster Preparedness Center).

An acute depletion of precipitation in late 1992 caused droughts with water shortage for production and livelihoods in 1993. In early 1993, the level of water storage in soil, rivers, and reservoirs was very low. Severe water shortages in the winter-spring 1992-1993 and summer-autumn 1993 crops were suffered in many areas throughout the country. The total area of winter-spring paddy fields affected by drought was over 176,000 ha (more than 22,000 ha died). The water level of rivers was lower than the average value by 0.1 to 0.5 m. Salinity penetrated deep into the estuaries, 10-20 km, sometimes down to 30 km. In July 1993, the water level of large reservoirs was below the dead level and continued to be exploited. Small and medium reservoirs were exhausted.

The rainy season in 1997 ended 1 month than usual, and in the first 6 months of 1998, the average precipitation was only 30-70% of the average. In the Mekong River Delta, there was almost no rain from March to June in 1998. The temperature in the early months of 1998 was higher than the average temperature by 1-3^{o}C. Intense heat waves occurred continuously in March, April and May 1998 in the southern region. The water level of the major rivers was 0.5-1.5 m lower than average. By the beginning of April 1998, small rivers and streams had significantly low flows. The water level of large reservoirs and some medium reservoirs was approximately at the dead level. Salinity intruded 15-20 km deep into the fields in the south. Many fresh water sources were affected by saltwater, seriously influencing irrigation and domestic water supply.

Drought and water shortage in the dry season of 1997-1998 caused acute damage with an affected area of rice crops being over 750,000 ha (over 120,000 ha dead), affected area of industrial and fruit trees being over 236,000 ha (nearly 51,000 ha died) and 3.1 million people lacking fresh water. The government had to support tens of billions of VND to provide domestic water for 18 provinces. Other losses that had not been statistically calculated included economic and environmental problems, erosion, desertification, food shortages, malnutrition, mental crisis and health impacts on millions of people.

In the first six months of 2002, a severe drought occurred, causing damages to crops and widespread wildfires in the natural forests of U Minh Thuong and U Minh Ha. The drought in 2004-2005 reached a large scale but was not as serious as in 1997-1998. In the Mekong Delta region, damage caused by drought and saltwater intrusion was 720 billion VND. In the Tien, Ham Luong, Co Chien and Hau rivers, saltwater intrusion was 60–80 km deep. Particularly in the Vam Co River, the intrusion reached a record depth of 120-140 km. (Meteorology and Hydrology Station of the South Central region, 2014.)

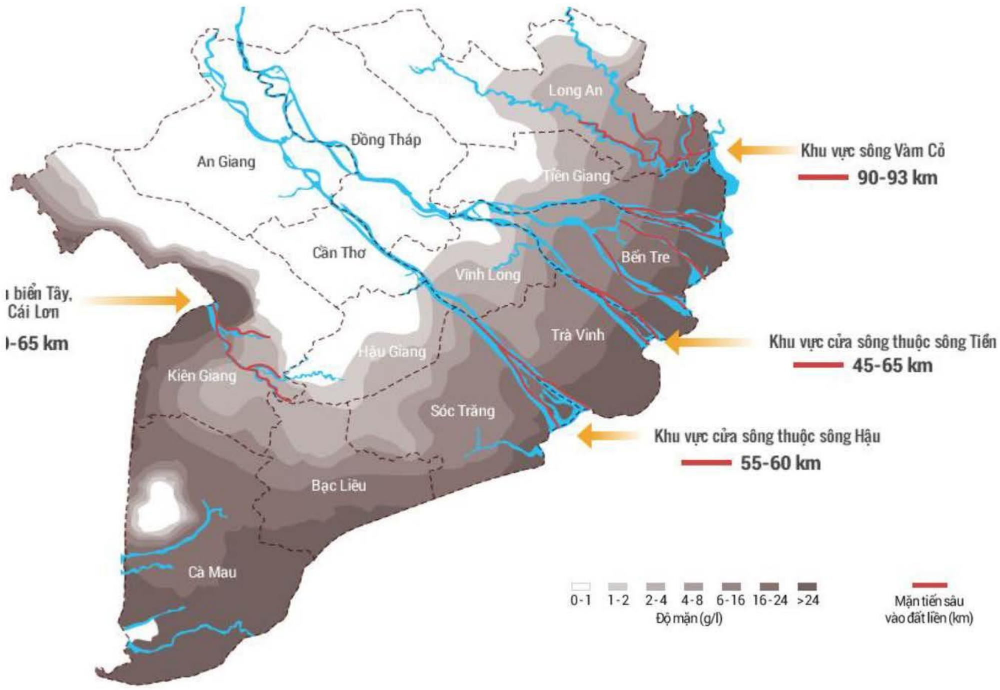


Figure 5. Saltwater intrusion map in 2016 (Disaster Management Policy and Technology Center, 2016)

Particularly in 2016, severe drought and saltwater intrusion inflicted the Mekong Delta, leading to the heaviest freshwater shortage in 100 years. Due to the late start and early end of the 2015 rainy season, the upstream of the Mekong River had the lowest water level in decades. Therefore, saltwater intrusion appeared earlier than the average of nearly 2 months, which had never appeared in the history of salinity monitoring. The highest extent of salinity intrusion into the soil was over 90 km. Saltwater intrusion seriously affected production and people's life, and the total damaged rice area was approximately 180,000 ha. Approximately 194,000 households and 900,000 people as well as many schools, clinics, hotels, and factories had insufficient water supply. As for forestry, many areas had a high fire alert, especially the two large forests of U Minh Thuong and U Minh Ha. In addition, high evaporation and the lack of fresh water supply affected the growth of fish and caused disease outbreaks. (Disaster Management Policy and Technology Center, 2016.)

4.2 The situation of drought and saltwater intrusion in 2020

The water level of the Mekong River dropped to a record before the dry season of 2019-2020, the lowest level in nearly 100 years. This made the Mekong Delta face saltwater intrusion occurring earlier, deeper and more seriously than in 2015-2016. Before the dry season began, there were many forecasts about drought and saltwater intrusion that might happen in the Mekong Delta.

According to Nguyen Van Tinh, General Director of the General Department of Irrigation - Ministry of Agriculture and Rural Development (MARD), in mid-December 2019, saltwater intruded 40-50 km inland, 3-5 km deeper than in 2016. In January, February and by mid-March 2020, the 4 g/l saline concentration penetrated into the mainland reaching depths of 55-110 km, which was 3-7 km more than the highest records. This salinity intrusion posed a great risk for the winter-spring crop in areas within 50-60 km from the coastline. Saline intrusion affected 10 of the 13 provinces in the Mekong Delta.

As a meteorological and natural fact, during the dry season, the water level of the Mekong River gradually decreases. The upstream of the Mekong River basin decreased, especially in the middle and lower parts of the river, and many locations recorded historically low water levels. In November 2019, the total flow of Cheang Sean station (Thailand) was 52% lower than the average value and 33% lower than in 2015. The flow of Kratie station (Cambodia) was 59% lower than the average value and 29% lower than in 2015. Additionally, the flow in the Tonle Sap (Cambodia) was much lower than the average by a total volume of 21.9 billion cubic meters. According to National Center for Hydrometeorological Forecast, Ben Tre province had reached 4 g/l salinity, indicating that the intrusion took place early and deep inland.

During the early dry season 2019-2020, the temperature in the Mekong Delta and across the country increased 0.5 to 1.5 Celsius degrees. Combined with that was the lack of rainfall, and in the dry months, the precipitation in the Mekong Delta and in the Mekong River basin was 20-30% lower compared to the average. A high risk of water shortage, drought and saltwater intrusion in the southern region in the dry season of 2019-2020 was identified. According to the National Center for Hydrometeorological Forecast, the upstream flow of the Mekong River continued to decline, from December 2019 to February 2020 with a shortage of 25-35%.

Saltwater intrusion in the early months of the dry season in the Mekong Delta provinces was deep. The extend of intrusion was estimated at 45-65 km, particularly in the Vam Co river area with the depth of over 70 km and provinces of Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Hau Giang, Long An and Kien Giang. Local authorities at different levels had issued newsletters and warned people not to be subjective to these natural disasters. (MONRE, 2019.)

The rainy season of 2019 in the Mekong basin appeared late, and the duration was short, and the total annual flow was estimated to be medium-low. The flow to the delta at the beginning of the dry season had decreased rapidly, to an extremely low level compared to the average value since 1980. Two important factors that manipulated the water resources and saltwater intrusion in the dry season 2019-2020 were the reserves in the Tonle Sap and the flow to Kratie (the upstream of the Mekong basin). As of November 27, 2019, the water storage in the Tonle Sap was at an equivalent level compared to the same period in 2015, and the water level on Mekong's mainstream was exceptionally low.

According to an assessment, saltwater intrusion in the dry season of 2019-2020 in the Mekong Delta region was relatively complicated (abnormally fluctuated), especially on days with combined high tides. In areas within 30-40 km from the coastline, in December 2019, salinity was estimated to exceed 4 g/l, but from January 2020 onwards, these regions were almost unable to find fresh water, causing a shortage of water for production and domestic use. In areas within 45 - 65 km from the coastline, from January 2020 to May 2020, had high salinity (> 4 g/l) intrusion. Areas farther than 70-75 km from the coastline, rarely encountered the saline intrusion of 4 g/l, but were still, nevertheless, the intrusive zone of salinity, affecting production and livelihoods. (Southern Institute of Water Resources Research, 2019.)

In extreme cases, prolonged periods of insufficient precipitation combined with the overuse and exploitation of water resources in the basin will cause longer and tougher drought, water shortage and intrusion periods. China announced the discharge of water on the Mekong River to help its neighbors cope with droughts, but there have not been any significant changes. In fact, the operation of Chinese hydropower dams in 2020 with low discharge started half a month later than the same period in 2018-2019.

As for damage, considerable agricultural production losses, insufficient domestic water and subsidence of canal banks were recorded, especially in Ca Mau, Ben Tre, Tra Vinh, Vinh Long, Kien Giang and Soc Trang provinces. Many steering activities had been implemented in localities to minimize the adverse effects of drought, water shortage and saltwater intrusion. (Vietnam Disaster Management Authority, 2020.)

4.3 Causes of drought and saltwater intrusion

According to To Van Truong, the main reasons for drought-exhaustion-salinity in the Mekong Delta were the occurrence of extreme climate and weather conditions and the facts that the higher the intensity, the longer the period and the stronger the expansion, finally, the greater the economic and environmental damage. There were also other minor reasons such as the impacts of the upstream flow, changes in the basin environment and the increase in water usage. The pace of urbanization in Vietnam has increased significantly. The supplement of aquifers from surface water was hence, limited. The over-exploitation of groundwater for domestic purposes and socio-economic development caused the depletion of groundwater while there was insufficient supplement to compensate the amount of extracted water. The rapid population growth combined with industrial and production development also put pressure on water resources and caused pollution issues. With the imbalance between saline and fresh water and the unchanged agricultural practices, salinity tended to move further inland. Therefore, the amount of water usage remained high, enhancing water pressure. (Vietnam Disaster Management Authority, 2020.)

The results of studies on saltwater intrusion in the Mekong Delta since 1980 show that the extend of the intrusion into the river mouths is strongly dependent on 6 factors: (1) Flow from the upstream of Mekong River; (2) Water storage capacity at the end of flood season in the Mekong Delta; (3) Evolution of coastal water levels; (4) Water usage in the Mekong Delta; (5) Shape of river bed and alluvium in the estuary areas and (6) Evolution of precipitation in the early rainy season. Monsoon is considered one of the contributors to enhance salinity, but this phenomenon is temporary, so it is only applied in specific cases, according to Nguyen Ngoc Anh, Former Director of Southern Institute of Water Resources Planning, (2016).

The flow from the upper Mekong was low, combined with the reduction of water resources in the early dry season due to reduced flood storage capacity, greater water usage for agricultural production in the Mekong Delta, and higher tidal water levels and wider estuary areas, which allowed the salinity boundary to penetrate deeper than before. Summarizing the above causes, the fact that salinity tended to be more intrusive and caused more severe consequences was understandable.

5 MATERIAL AND METHODOLOGY

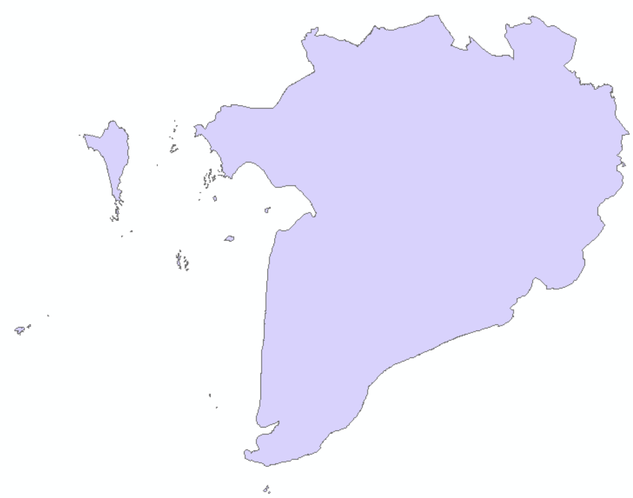
In this section, a detailed information on the materials and methodology will be introduced. The used materials majorly include the numerical and spatial data of the Mekong Delta under an environment of the Geographic Information System. The methodology has the Kriging interpolation algorithm as the center.

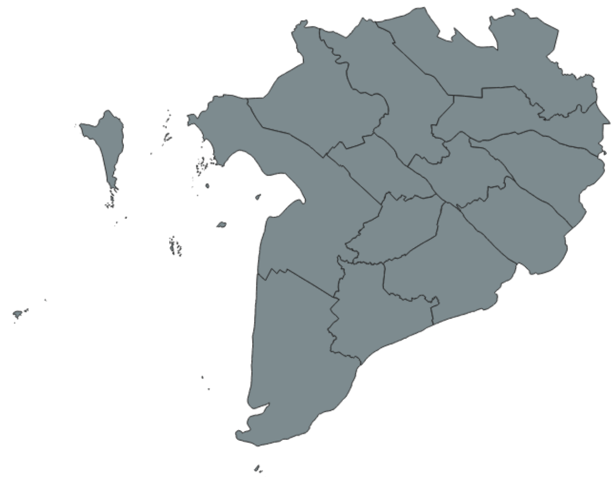
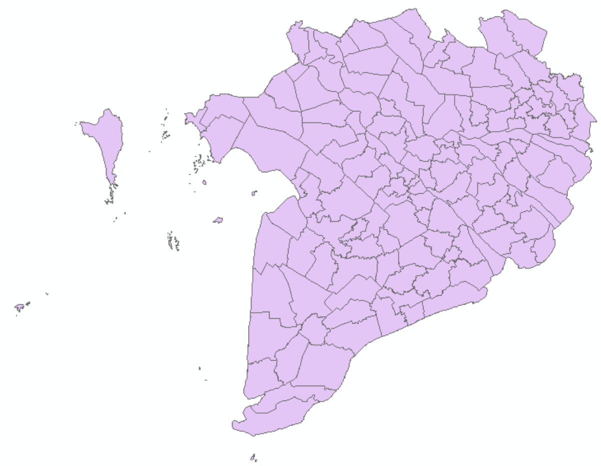
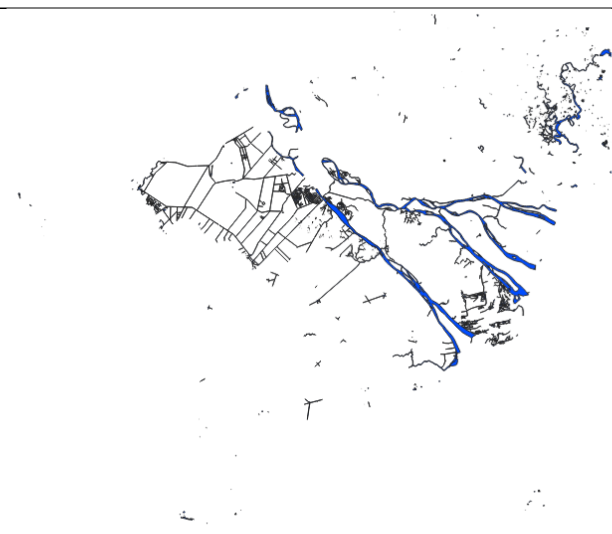
5.1 Material

This study used ArcGis10 Software. This Geographic Information System (GIS) software was utilized to process and visualize data and enter attribute information of sampling points for data collection. The main application used was ArcMap. This application helps users to display and explore GIS datasets for the studied area, assign symbols, create map layouts for printing or publication, and create and edit datasets. ArcMap represents geographic information as a collection of layers and other elements on a map. Common map elements comprise the data frame containing map layers for a given extent and a scale bar, north arrow, title, descriptive text and a symbol legend. The data acquired for the study included:

- The Mekong Delta basemap data in shapefile format, including spatial data and attribute data provided by GADM (the Database of Global Administrative Areas) and Humanitarian OpenStreetMap Team (HOT) (Table 3).
- Salinity monitoring data provided by news from the National Center for Hydrometeorological Forecasting from December 2019 to April 2020.
- Location data of salinity monitoring stations on the Mekong Delta from Vietnam Center of Hydrometeorological data.
- Aggregate data on the agricultural production of the Mekong Delta from Vietnam's online agricultural atlas, provided by the General Statistics Office and other agencies such as the Ministry of Agriculture and Rural Development and the Ministry of Natural Resources and Environment.

Table 3. Spatial data of the Mekong Delta

Description	**Spatial data**
Administrative boundary of the Mekong Delta	

Administrative boundaries at the province and city level of the Mekong Delta	
Administrative boundaries at the district level of the Mekong Delta	
The system of rivers and lakes in the delta	

5.2 Methodology

The study was implemented through the following steps:

- Collecting GIS data (attribute and vector data), and salinity indicators to be monitored in the Mekong Delta from December 2019 to April 2020 (the dry season of 2019-2020) were collected. Other data including information on the study area, locations of salinity measuring stations, statistical data on population and agricultural production was also acquired.
- Developing the Mekong Delta's basemap, based on the administrative boundaries and the system of rivers and lakes.
- Locating salinity measuring stations in the studied area.
- Building maps of population distribution and agricultural production areas in the Mekong Delta.
- Evaluating salinity measurement data on the stations and calculating average salinity over time.
- Interpolating the salinity by Kriging method and creating salinity zoning map for the Mekong delta.
- Combining above elements with maps of population distribution and production areas to assess and estimate the impact of saltwater intrusion in 2019-2020.
- Proposing solutions and recommendations for saltwater intrusion problems in the Mekong Delta.

Currently, there are many available interpolation algorithms, each having its advantages and disadvantages. In this study, Kriging algorithm was used to interpolate values for points around a predefined value point. The nearer points will be more affected than the remote points. Kriging uses a weight, which assigns more influence to the nearest data points in the interpolation of values for unknown locations and depends on spatial relationships and statistics for surface calculations. Kriging's process begins with semivariance estimation followed by interpolation (Nguyen, 2014).

Kriging is a group of techniques used in geostatistics to interpolate a value of a random field (such as the z-height of a terrain) at a point that cannot be physically measured from nearby points, expressed by Equation 1.

$$T^* - \quad = \sum_1^n W_i (g_i - \mu_i) \tag{1}$$

Where

T*: value to be estimated at 1 coordinate in space.

μ: mean value.

W: the weight depends on the location of data.

g_i: value of other points.

n: number of surrounding data used to estimate T value.

This interpolation method has several advantages. The values of the assigned points depend not only on the distance but also on their spatial distribution, making the interpolation values more spatially correlated. This is a method with higher accuracy that helps in finding out some common properties of the entire surface represented by measurement values, and then applying those properties to other parts of the surface. However, it requires significant time for calculation and modeling and needs many options and input requirements from users. Kriging is affected by both the relationship of the sample points and their directions and heavily depends on spatial relationships and statistics to calculate the surface's properties.

5.2.1 Collecting data

Basemap data of the Mekong Delta was collected in the shapefile format, including the administrative boundary of the Mekong Delta and administrative boundaries at province, city and district levels of the Mekong Delta collected from GADM (updated June 2018) and the system of rivers and lakes from Humanitarian OpenStreetMap Team (HOT) (updated April 2020).

Salinity monitoring data in the Mekong Delta during the dry season from December 2019 to April 2020 was collected with a total of 23 bulletins from the Vietnam National Center for Hydrometeorological Forecasting (a new bulletin had been released every 5-10 days). The salinity measurement data was taken as the highest salinity concentration (Smax) in a period of 5-10 days (depending on the bulletins), in the unit of g/l. The data had been compiled from 54 salinity measurement stations, but not all the salinity measurement data at each station was included in the bulletins. The location data of 54 salinity measuring stations was determined from the Vietnam Center of Hydro-meteorological Data (with their longitudes and latitudes).

The data on the livelihood and agricultural production in the Mekong Delta from the online Agricultural Atlas of Vietnam, provided by the General Statistics Office and other agencies such as the Ministry of Agriculture and Rural Development and the Ministry of Natural Resources and Environment, was collected basing on 8 criteria: total population, total area of agricultural land, area of rice, area of annual crops, perennial crops, fruit trees, forest, and aquaculture. These figures were collected from the statistics of 2016 that did not change much in 2019-2020. These indicators were statistically calculated by localities (at the district level) in the Mekong Delta.

5.2.2 Developing the basemap

The basemap was extracted from GADM dataset of Vietnam with 13 provinces and cities in the Mekong Delta, including An Giang, Bac Lieu, Ben Tre, Ca Mau, Can Tho, Dong Thap, Hau Giang, Kien Giang, Long An, Soc Trang, Tien Giang, Tra Vinh, Vinh Long.

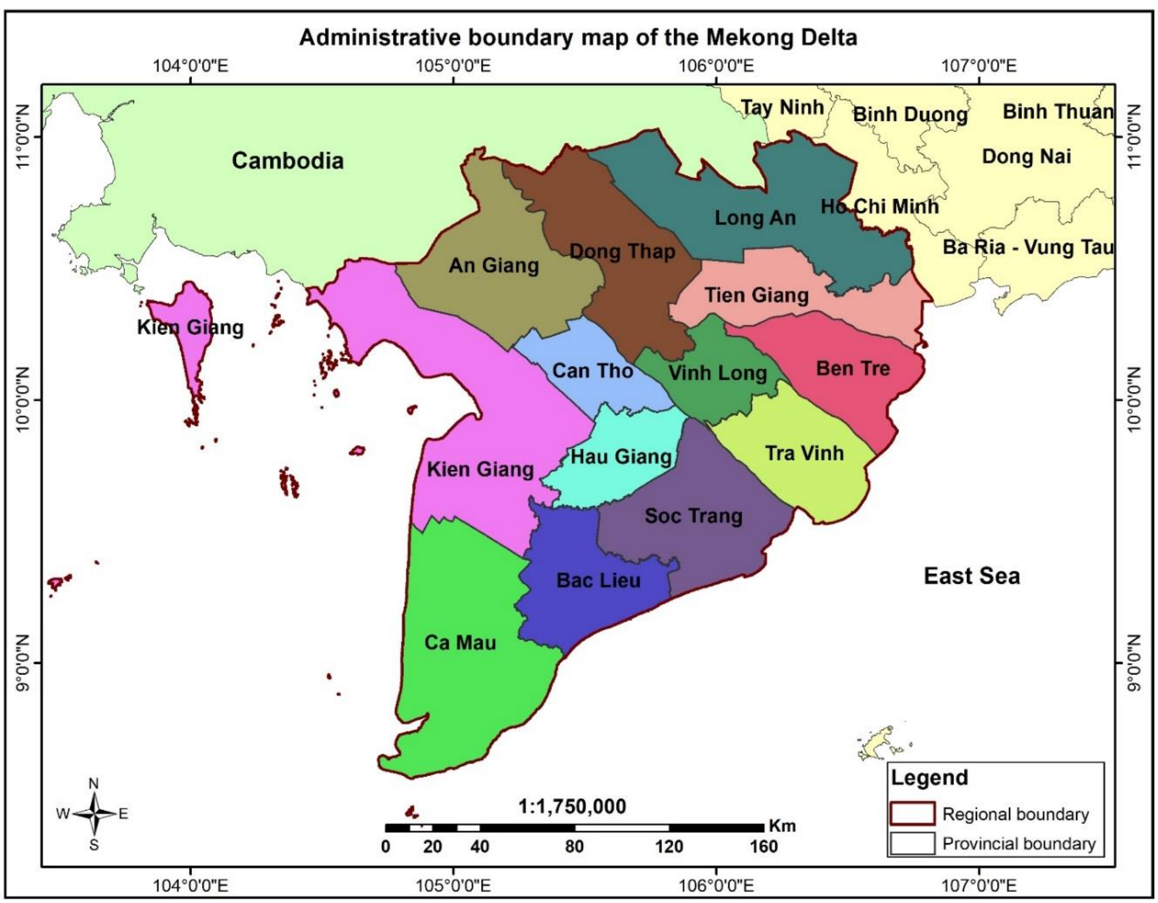


Figure 6. Administrative boundary map of the Mekong Delta

5.2.3 Locating salinity measuring stations

A new dataset of salinity measuring points was created by entering the coordinates of the points to build a layer of locations of the salinity measuring stations in the Mekong Delta, and combining it with the system of rivers and lakes in the studied area for a better visualization of the salinity measurement locations.

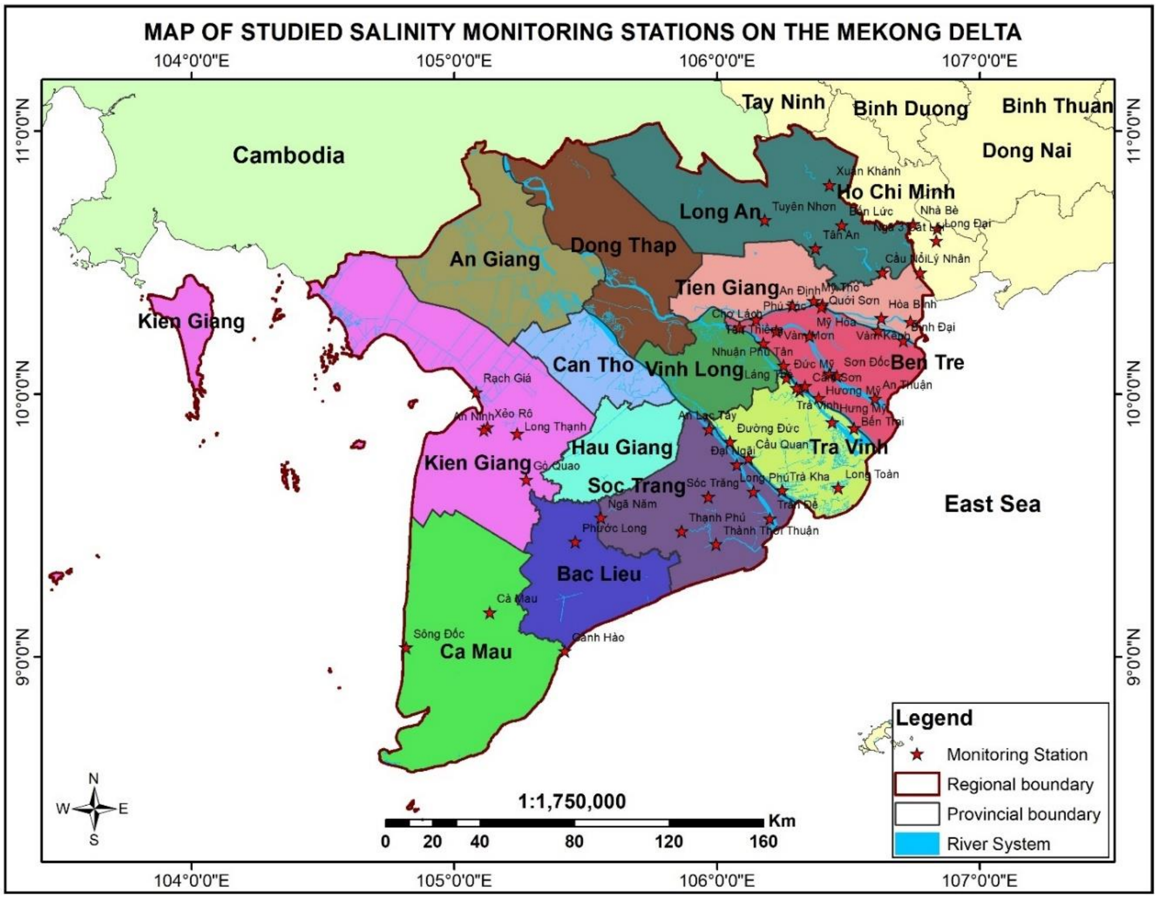


Figure 7. Map of studied salinity monitoring stations in the Mekong Delta

The 54 salinity measuring stations were located close to the estuaries and the coastal area, concentrating mainly in provinces near and bordering with the sea, including Long An, Tien Giang, Ben Tre, Tra Vinh, Soc Trang and Kien Giang, which were more vulnerable to saltwater intrusion. There were also some infield stations in Ca Mau, Bac Lieu and Soc Trang provinces.

5.2.4 Building maps of population distribution and agricultural production areas

The data on population, agricultural area, rice cultivation, annual and perennial crops, fruit trees, forest and aquaculture areas were entered in the attribute table of the Mekong Delta's districts and converted into data in the form of attributes for easier mapping of the living and production situation.

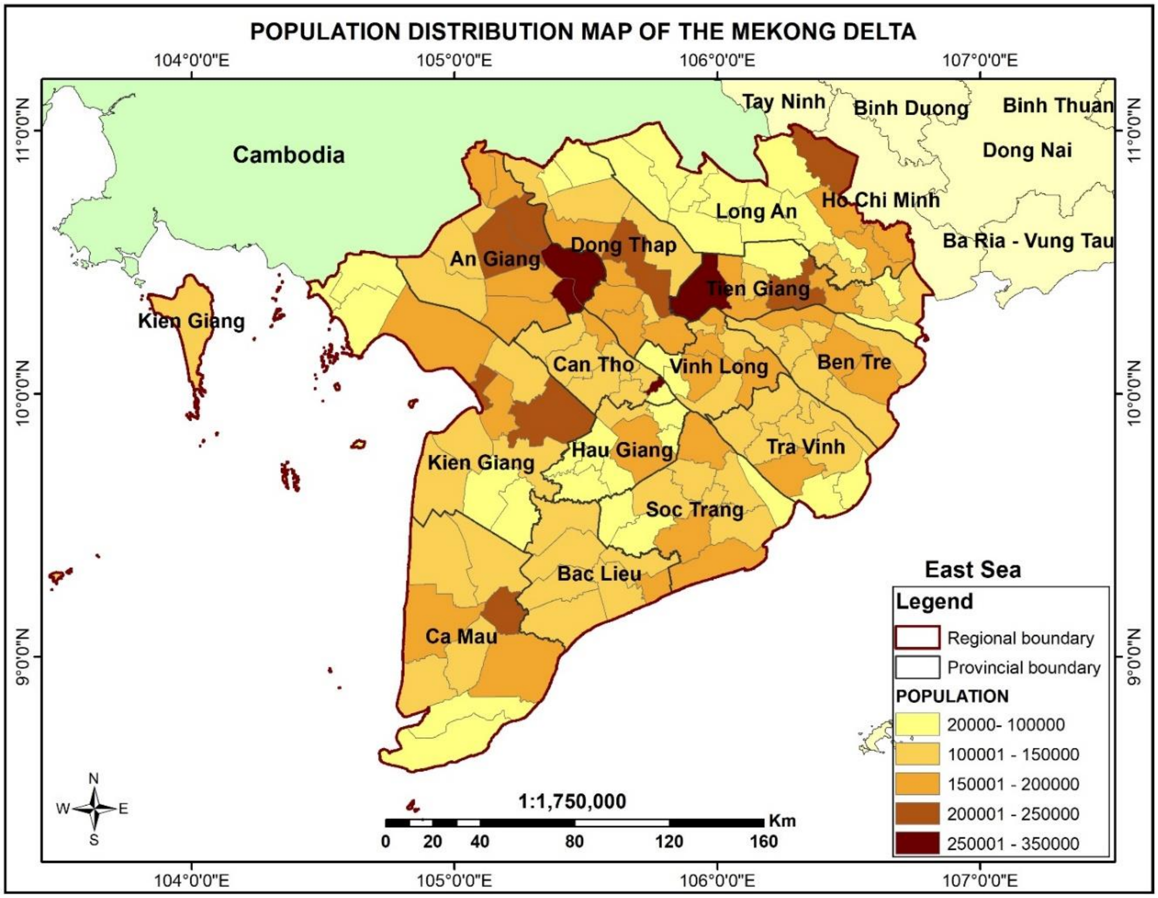


Figure 8. Population distribution map of the Mekong Delta

The population in the Mekong River Delta was unevenly distributed and concentrating in districts such as Cho Moi (An Giang), Cai Be (Tien Giang), Ninh Kieu (Can Tho) and Long Xuyen city (An Giang). The population was low in the districts of Long An province and some coastal districts (where salinity intrusion was most likely to happen) such as Nam Can, Ngoc Hien (Ca Mau), Kien Hai, Giang Thanh, and Ha Tien (Kien Giang), Duyen Hai (Tra Vinh) and Cu Lao Dung (Soc Trang) districts (with a population smaller than 100,000).

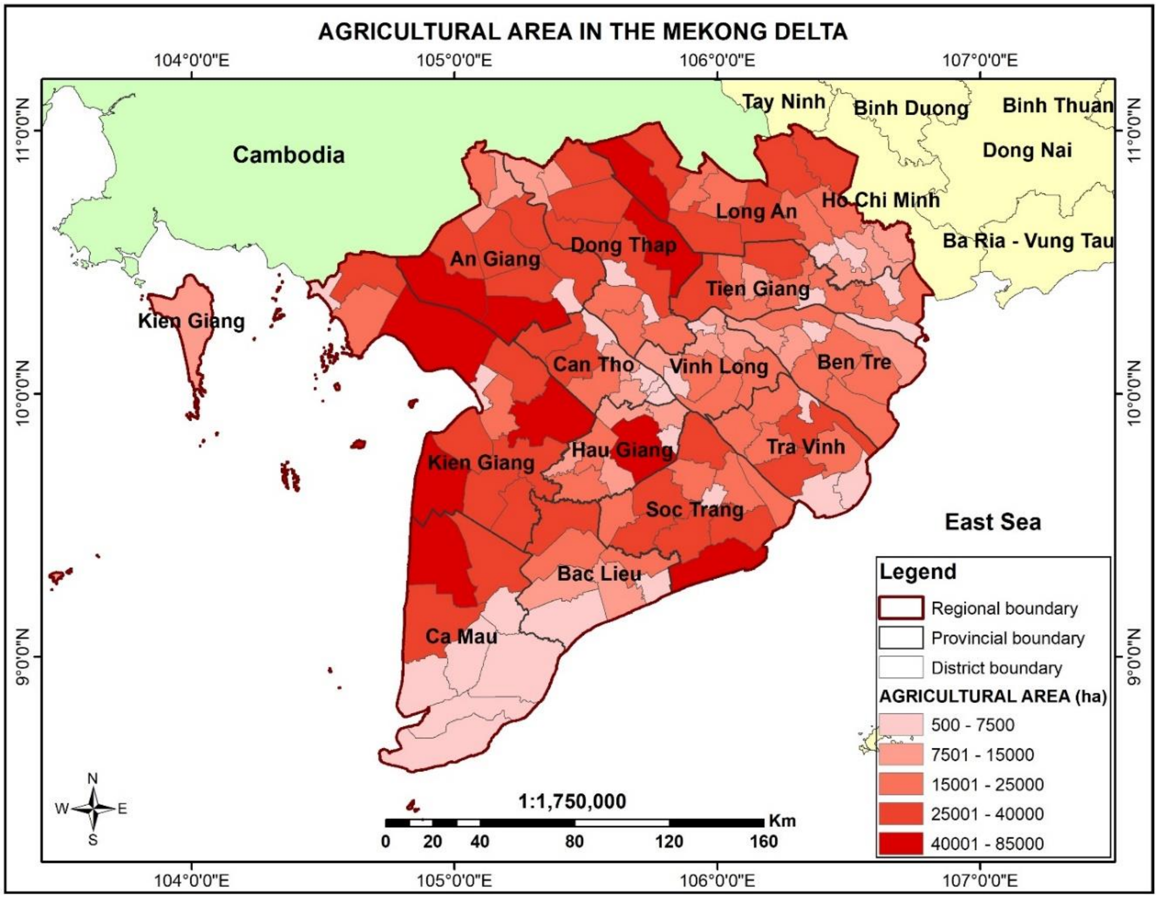


Figure 9. Agricultural area in the Mekong Delta

Most regions in the Mekong Delta had large areas of agricultural production, but the distribution of agricultural land was uneven. Kien Giang province had districts such as Hon Dat, Giong Rieng and An Minh, with large areas of agricultural land (greater than 40,000 ha). Agricultural land was sparser in the provincial cities and urban districts of Can Tho City as these were places with higher economic development conditions than other areas. An agricultural area with exceptionally low density was located in the southernmost region of the Mekong Delta, in the districts of Nam Can, Ngoc Hien, Phu Tan, Dam Doi, Cai Nuoc (Ca Mau) and Dong Hai (Bac Lieu). Parts of Tra Vinh also had less agricultural production area than neighboring areas (<7500 ha).

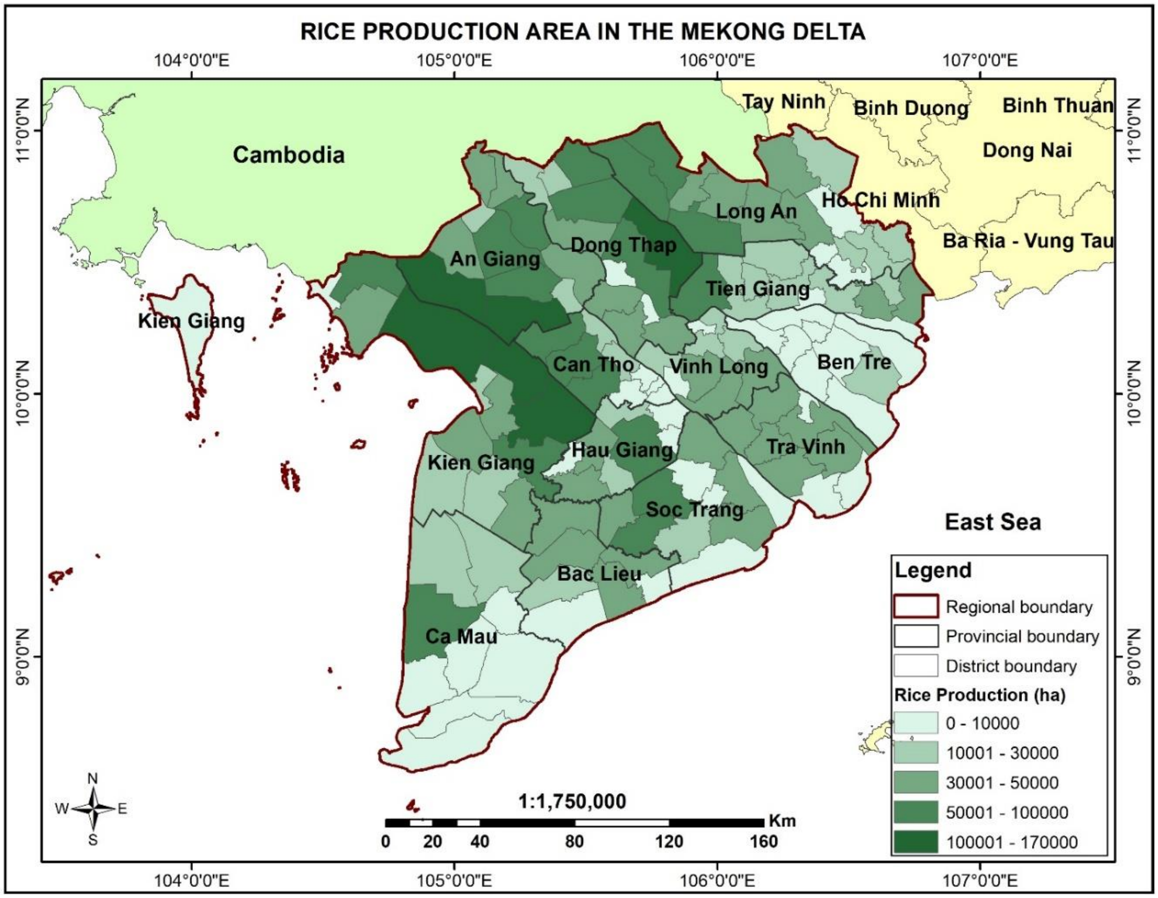


Figure 10. Rice production area in the Mekong Delta

The Mekong Delta proved to have a particularly high annual rice area compared to other regions in Vietnam. Annual rice area seemed to be most concentrated in Kien Giang (Hon Dat, Giong Rieng and Tan Hiep districts), An Giang (Tri Ton, Thoai Son and Chau Phu districts) and Dong Thap (Thap Muoi and Cao Lanh districts). The lowest total rice area was recorded in Ben Tre and Ca Mau provinces. The annual rice area was particularly low in the districts of Cho Lach, Mo Cay Bac, Mo Cay Nam (Ben Tre), Dam Doi, Ngoc Hien, Phu Tan, Nam Can, Cai Nuoc (Ca Mau) (with the area smaller than 200 ha/year).

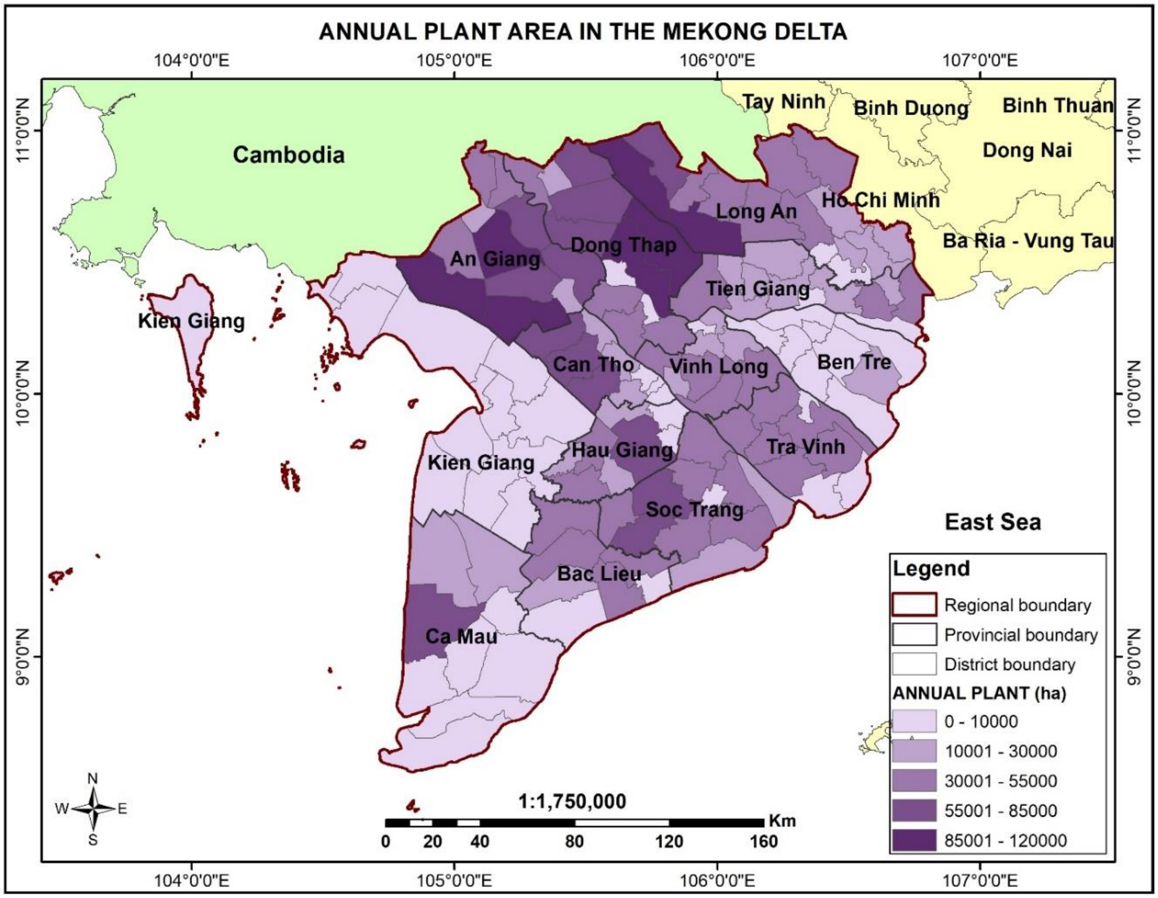


Figure 11. Annual plant area in the Mekong Delta

Similarly, a distribution of the area planted with other annual crops (maize, sugarcane, cotton, peanuts and soybeans) was analyzed. The area of annual crops was highly concentrated in provinces of An Giang (Tri Ton, Thoai Son, Chau Phu, Chau Thanh districts), Dong Thap (Thap Muoi and Cao Lanh districts) and Long An (Tan Hung, Tan Thanh districts). The area with the lowest amount of these crops was found in Kien Giang, Ben Tre and Ca Mau provinces, since coastal provinces were at a higher risk of saline soils.

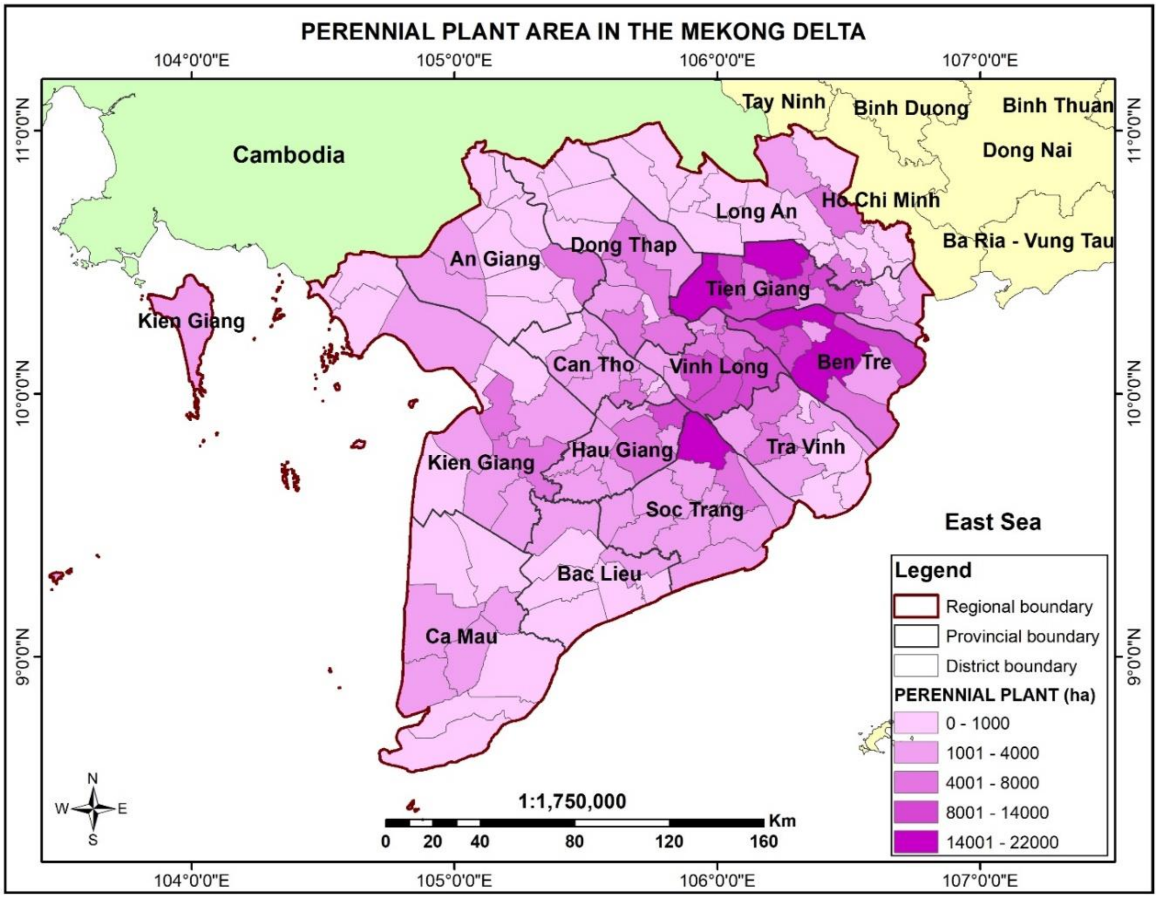


Figure 12. Perennial plant area in the Mekong Delta

The perennial crop area (for example, cashew, rubber, coffee, tea and pepper) in the Mekong Delta was unevenly distributed. The provinces with the largest area of perennial crops included Tien Giang (Cai Be, Tan Phuoc, Cai Lay, Cho Gao, Chau Thanh districts), Ben Tre (Giong Trom, Mo Cay Nam, Mo Cay Bac, Chau Thanh, Cho Lach districts), Vinh Long (Vung Liem, Tra On), Soc Trang (Ke Sach). In contrast, the provinces with low perennial plant area included An Giang, Bac Lieu, Ca Mau, Dong Thap, Kien Giang and Long An with many districts having an area of perennial crops less than 500 ha.

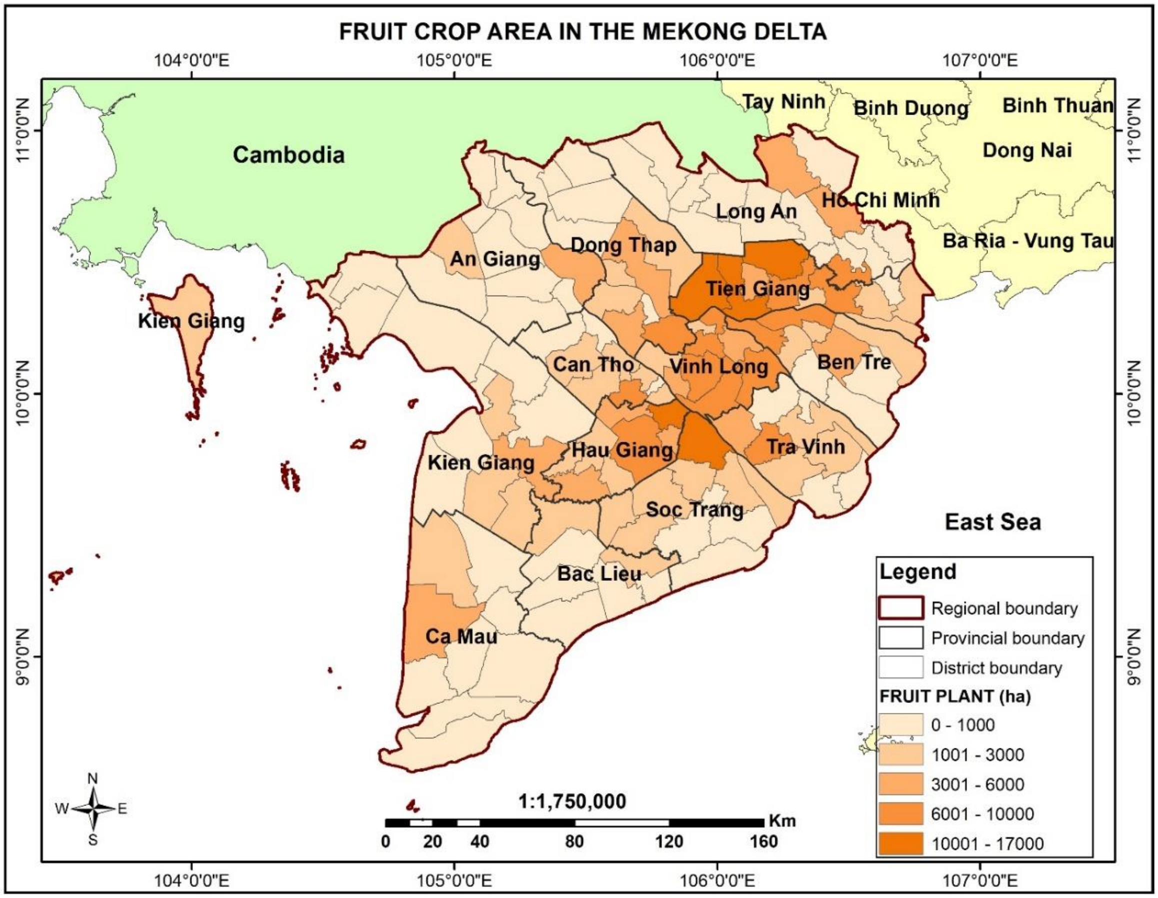


Figure 13. Fruit crop area in the Mekong Delta

The area of fruit trees (such as grapes, mangoes, oranges, tangerines, longans and rambutans) in the Mekong Delta was also unevenly distributed. Most of these trees were grown and exploited in provinces such as Tien Giang, Vinh Long and Hau Giang. There were many districts with an area of fruit trees of approximately 10,000 hectares. Ke Sach district of Soc Trang province also had a large fruit tree growing area of approximately 14,000 ha, but other districts in Soc Trang did not grow many fruit trees. Provinces with small areas of fruit plant included An Giang, Bac Lieu, Ca Mau, Kien Giang and Long An with many districts having an area less than 500 ha of fruit trees.

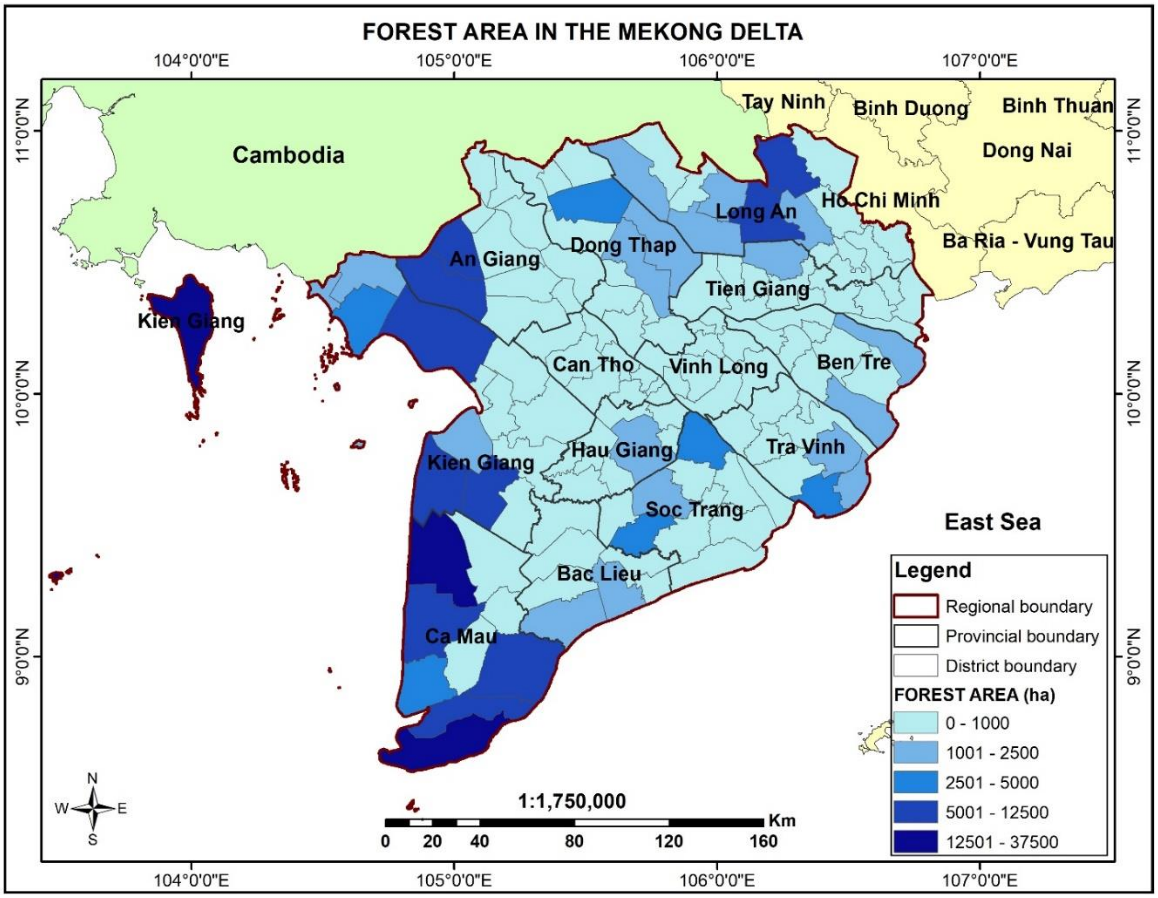


Figure 14. Forest area in the Mekong Delta

The Mekong Delta had a relatively low total forest area compared to the national average, comprising mostly coastal protection forests because most of the area was composed of alluvial and saline soils, suitable for agricultural production and aquaculture. The total forest area of the Mekong Delta was concentrated in the cape of Ca Mau (mangrove forests) and Kien Giang (including U Minh Thuong National Park and in Phu Quoc Island District with Phu Quoc national park and forests). In addition, there were Tra Su Cajuput Forest (An Giang) and Tan Lap Cajuput Forest (Long An). In other provinces and regions in the Mekong Delta, the area of forest was considered small or insignificant. Mangrove forests in the Mekong Delta play an important role in the context of climate change in the region. Mangroves help slow the flow and the expansion of the tides. Due to the dense root system, mangroves prevent damage from tides and sand, help to accumulate silt and local humus, and bring additional benefits by slowing the water flow and quickly adapting to the rising sea level. Owing to the propagules (seedlings), fruits and seeds that can survive for a long time in the water, mangroves can spread widely into the mainland irrespective of the rising sea level. They greatly reduce the height of tides, protecting sea dikes, especially restricting salinity intrusion and preserving groundwater. The Mekong Delta mangrove forests also bring biodiversity to the region.

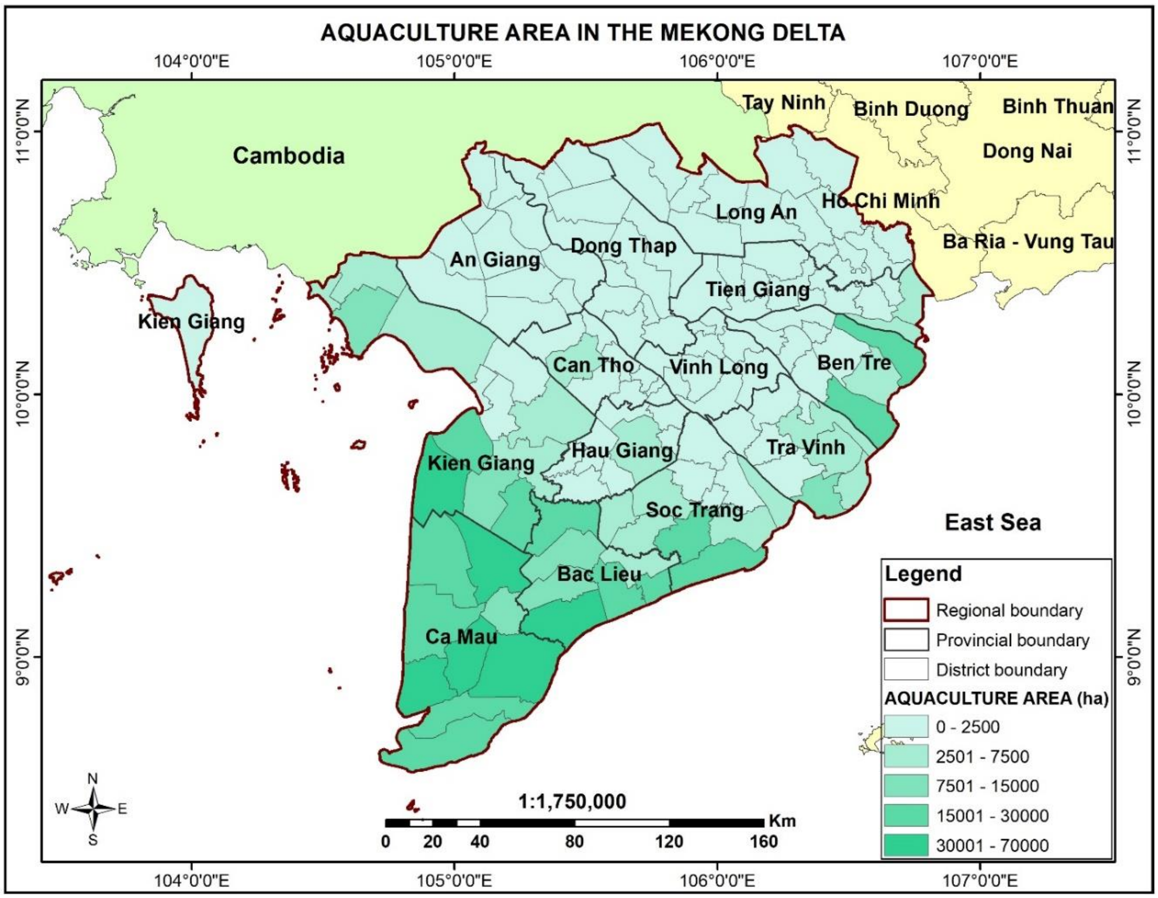


Figure 15. Aquaculture area in the Mekong Delta

With the benefits of natural resources from the sea and the natural salinity, coastal provinces in the Mekong Delta have advantages in aquaculture. The Mekong Delta has the largest aquacultural area in the country. The key provinces for aquaculture in the region include Ca Mau, Kien Giang, Bac Lieu, Soc Trang and Ben Tre with many districts having an aquacultural area of more than 10,000 ha, while other locations have small or negligible aquaculture area.

5.2.5 Evaluating salinity measurement data

After summarizing the salinity measurement data, it was connected with the attribute table of the salinity measurement points to be converted into attribute data. Kriging interpolation method in ArcGIS software was used to create salinity maps at each measuring time, therefrom building a salinity time series.

Salinity levels were classified into 5 categories based on the salinity threshold affecting the agricultural production of 4 g/l: (1) salinity less than 4 g/l (no effects); (2) salinity ranges from 4 to 8 g/l (slight or minor effects); (3) salinity ranges from 8 to 16 g/l (medium effects); (4) salinity ranges from 16 to 24 g/l (high effects); (5) salinity greater than 24 g/l (very high effects, unable to develop agricultural production). This was based on the saltwater intrusion report of 2016 by the Southern Institute of Water Resources Research and the definition of saltwater intrusion by the Center for Disaster Management Policy and Technology.

In the period from December 21, 2019, to January 31, 2020, due to incomplete measurement data from the salinity measuring stations, which could be likely to produce inaccurate results, Kriging method should not be applied for mapping salinity intrusion for these days in the timeseries. The timeseries of salinity intrusion images were conducted for the period of February 1, 2020, to April 30, 2020 (Appendix 1). The general features of the intrusion in the study periods were quite similar. It can be seen that salinity measurement data at a station did not change much over time, hence, these data were averaged to provide a better overview of salinity intrusion in the Mekong Delta.

6 RESULT

Based on the average statistics table (Appendix 2), Kriging interpolation was used to create a map of saltwater intrusion in the Mekong Delta in the dry season of 2019-2020 (Figure 16).

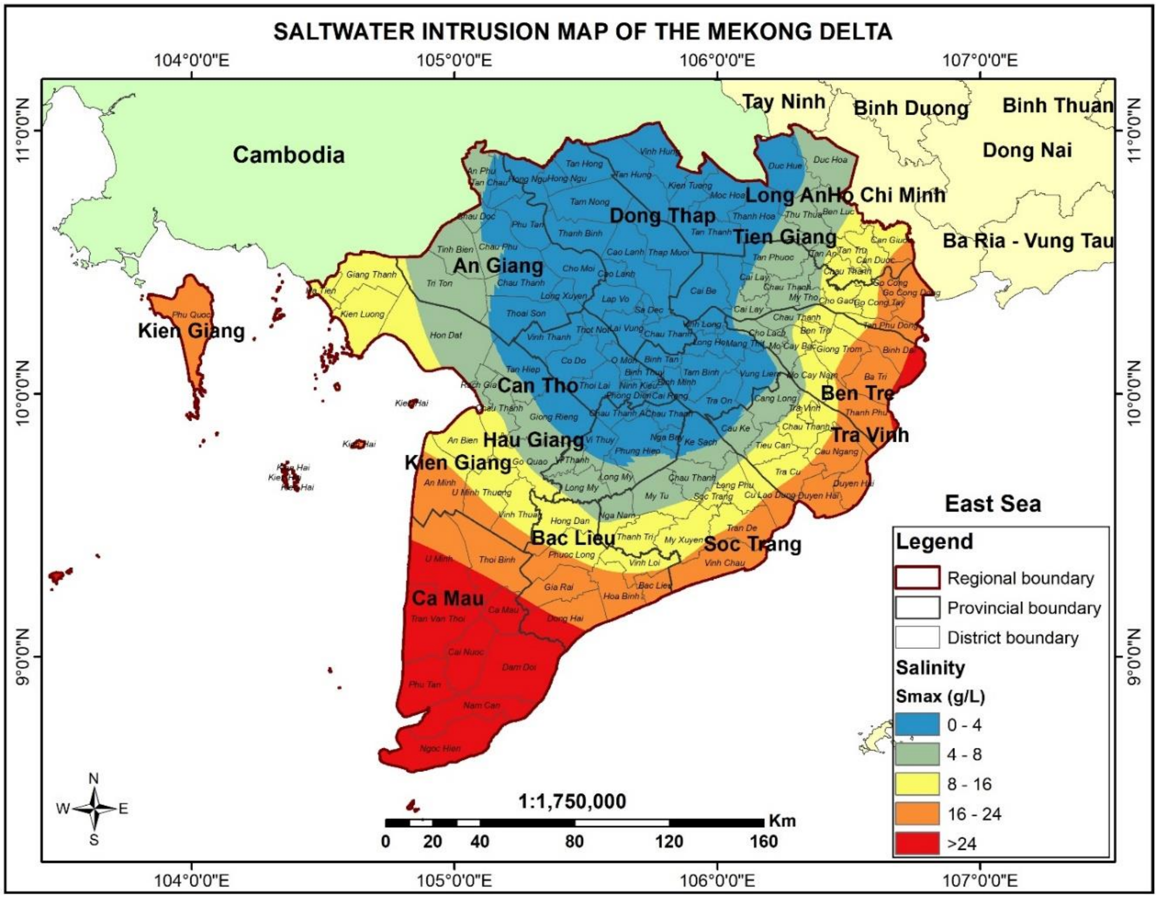


Figure 16. Saltwater intrusion map of the Mekong Delta 2019-2020

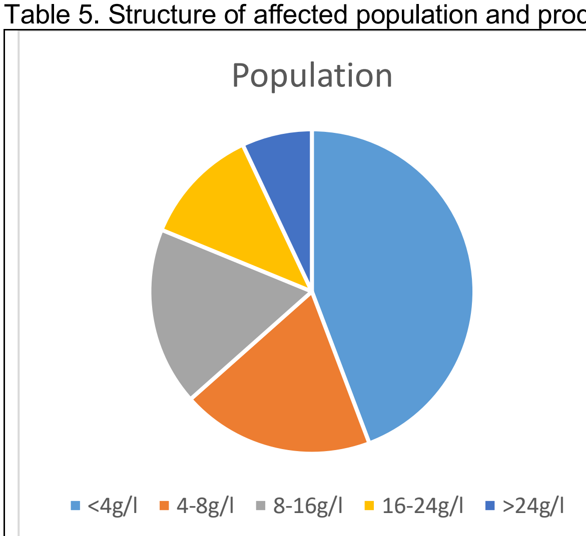
The map shows a clear hierarchy of salinity levels in the area. Salinity decreased gradually with the direction from the coast into the mainland. Highly saline areas were included as the prediction and the annual saltwater intrusion characteristics in the Mekong Delta. The greatest concentration was estimated in the southernmost region, covering most of the area of Ca Mau province, while the provinces of An Giang, Dong Thap, Vinh Long, Hau Giang and the city of Can Tho did not have a significant level of salinity. The total area with salinity less than 4 g/l was 1,357,100 ha (accounting for 33.71%), the area with salinity ranging from 4 to 8 g/l was 748,650 ha (accounting for 18.60%), the area with salinity ranging from 8 to 16 g/l was 751,200 ha (accounting for 18.66%), the area with salinity ranging from 16 to 24 g/l was 693,850 ha (accounting for 17.24%) and finally, the area where salinity was greater than 24 g/l was 474,900 ha (accounting for 11.80%). The estimated locations of five salinity levels are shown in Appendix 3.

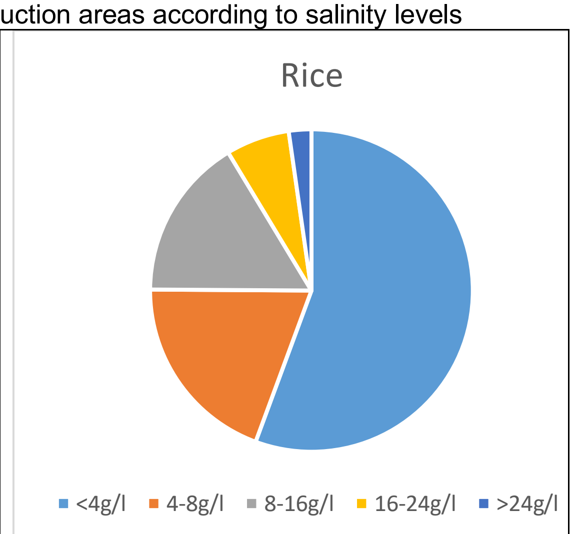
Table 4. Affected population (unit: person) and production areas according to salinity levels (unit: ha)

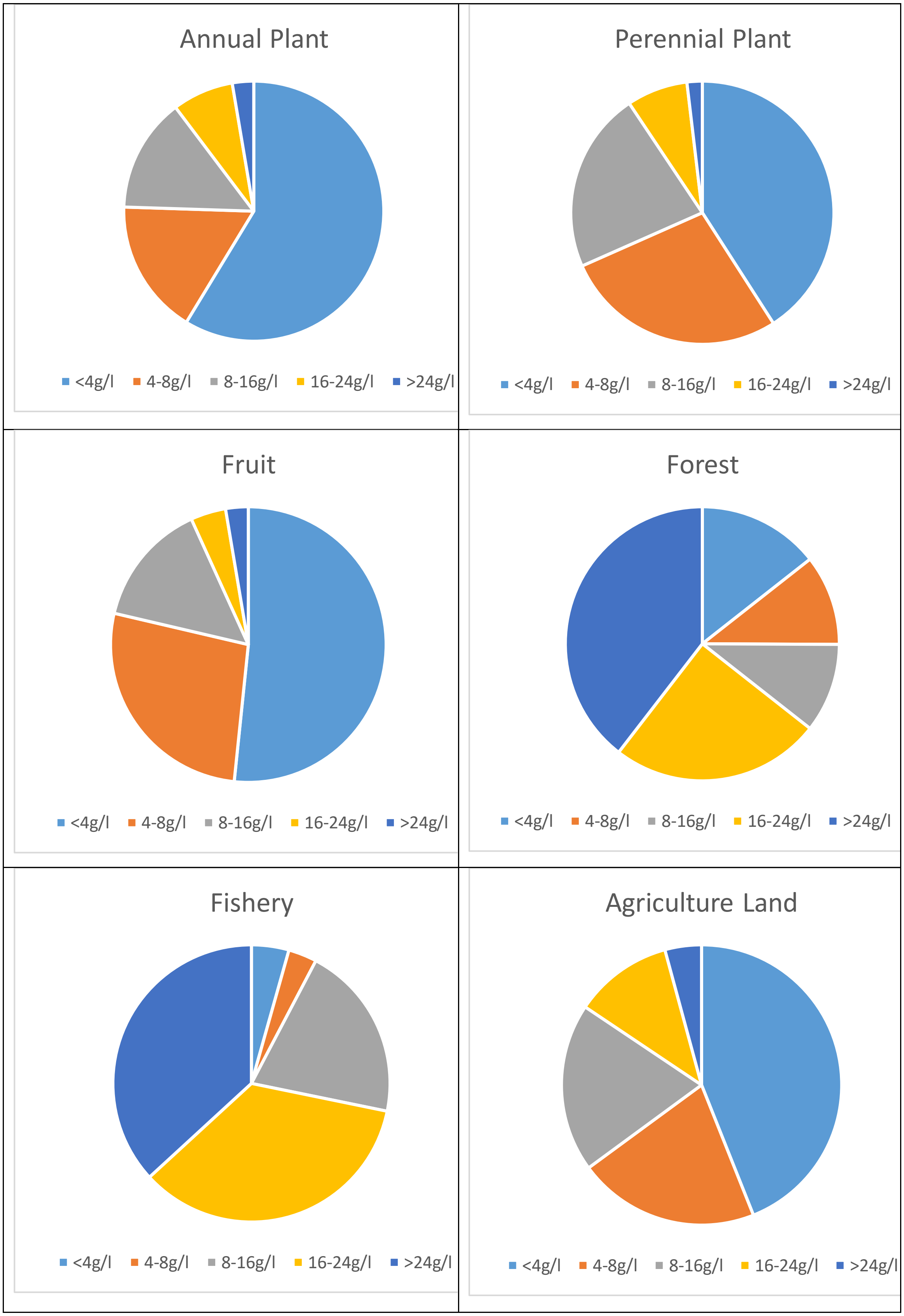
Salinity Levels	Population	Paddy	Annual	Perennial	Fruit	Forest	Fishery	Agriculture
1	7821296	2355642	2322627	184065	166288	34915	34035	1188216
2	3391861	824717	665700	123548	86975	25861	25967	566377
3	3142103	688929	562377	100132	46891	25535	159933	526368
4	2084138	269658	301687	33732	13302	60260	272478	307515
5	1236492	95920	105311	8459	8547	95854	287039	114058

Based on the created saltwater intrusion map, the numbers of affected population and production areas according to the predefined salinity levels are summarized in Table 4. Most of the region's population and production areas were inside the safer salinity zone (with minimal to medium effects), while a minority were located in the more dangerous zone, i.e., at levels 4 and 5 (with high effects). The results somewhat reflect the experience of the residents and agricultural practices towards reoccurring saltwater intrusion.

Table 5. Structure of affected population and production areas according to salinity levels







It can be seen from Table 5 that approximately half of the area occupied by agricultural production, rice, annual plant, perennial plant, fruit and half of the population in the Mekong Delta were forecast to be at risk of being affected by saline intrusion, of which approximately 10% was highly affected by the disaster. Even though it was much smaller than the proportion of other safer zones, this was still considered to be notable since it can cause significant damage to the lives of people and the socio-economic situation in the region. As a rule, mangroves and aquaculture were able to adapt to higher salinity and were less affected than the other categories, so most of high salinity areas were occupied by mangroves and aquaculture.

7 DISCUSSION

In agricultural production, salinity of soil and water plays a decisive role in the selection of cultivated objects and the arrangement of crops. Based on long-term farming experience, farmers can arrange appropriate crop structures to minimize the harmful effects of salinity intrusion. Rice is one of the crops that is most affected by saltwater intrusion. Fresh water sources are mainly used for the cultivation of rice. The forms of cultivation that can be adapted to or are less affected when the salinity changes, such as saltwater shrimp farming and salt fields need fewer structural season modifications. However, for the purpose of reviewing and zoning of saltwater intrusion, these aspects need to be considered.

Depending on the nature and extent of salinity intrusion, combined with improvement factors such as the initiative of irrigation in the dry season and construction of freshwater storage dams (generally referred to irrigation works) to cope with the sea water intrusion, and the scale of influence in each region, different farming methods should be applied. Since salinity occurs in cycles, it is possible to proactively respond and introduce farming practices adapted to saline intrusion.

The current status of crop structure and agricultural products reflects the extent of saltwater intrusion. The regions with high salinity are typically areas of saltwater aquaculture and protection forests (mangrove forests). Areas with average salinity are suitable for brackish water aquaculture and short-term crops, especially at the beginning of the rainy season to take advantage of natural fresh water. The least affected areas are mainly cultivated with rice, fruit trees, annual crops and perennial crops.

7.1 Strengths of the research method

The method used in this study was fairly simple to use. In order to run the algorithm, only one data layer with data of salinity measurement and coordinates of stations was required. The used software had a simple, user-friendly design and interface. With several simple steps in collecting and entering data and running algorithms, objective information of salinity intrusion could be acquired on. This was a method suitable for conducting research with a limited budget.

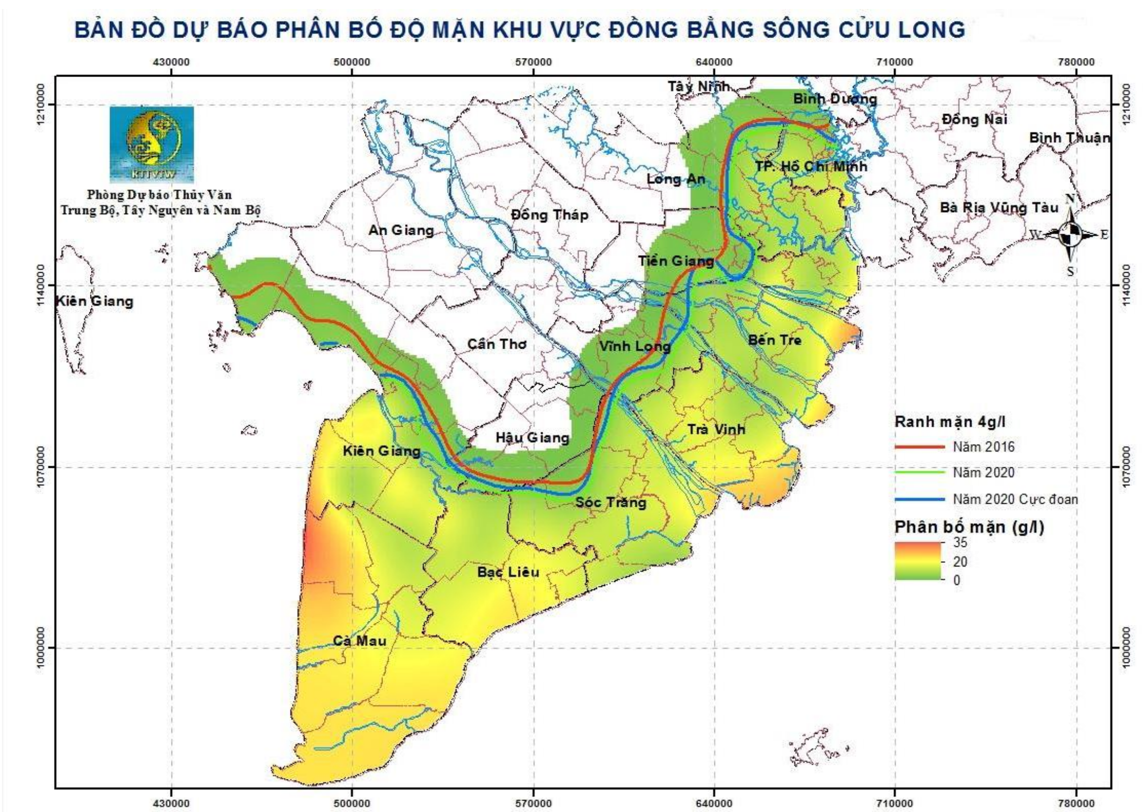


Figure 17. Forecast map of salinity distribution in the Mekong Delta (National Center for Hydrometeorological Forecasting, 2020)

Compared with the forecast map of saline water intrusion in the Mekong Delta in the dry season 2020 (Figure 17), the results of this study had similar features. Salinity levels were clearly decentralized, gradually decreasing from the coast to the mainland.

Recently, the application of science and technology in monitoring and assessing saltwater intrusion has been conducted by Vietnamese scientists under different methods. In the study of Tran Quoc Dat et al. (2012), salinity intrusion in the Mekong Delta was simulated for different scenarios of sea level rise and decreasing downstream discharge by MIKE11 model. MIKE11 is a unidirectional hydrodynamic model for simulating uneven flows on rivers and canals. The updated model's database included all salinity prevention works in the delta, collected from The Southern Institute of Water Resources Research (SIWRR), Mekong River Commission (MRC) and Project Management Unit no.10 (PMU10). The hydraulic module and diffuse load module in MIKE11 were applied for simulation of saltwater intrusion in this model. This is a software that can integrate features for creating simulation models, with a high degree of complexity and accuracy, but it requires experience with model runners and a great amount of input data sources as well as financial resources to run the software.

In another saltwater intrusion evaluation for Tra Vinh province by Nguyen Nguyen Vu et al. in 2018, remote sensing and GIS techniques were integrated in monitoring and creating a salinity intrusion map. The data was obtained from Landsat 8 satellite images combined with salinity monitoring data collected from field monitoring stations during the dry season. However, there are some limitations in remote sensing data such as low image resolution, inconsistency due to environmental conditions, and spectral confusion between objects, which makes it difficult to interpret objects on images or reduce the accuracy of results. The results can provide visual information to be combined with models of tides and upstream flows to create early warning systems.

In other studies, MODIS data was applied to identify areas of agricultural cultivation, therefrom, zoning saltwater intrusion in the region. These studies analyzed temporal series of images with normalized difference vegetation index (NDVI) on spatial resolution MODIS data in combination with Landsat 8 satellite images to create a map, then determining the cultivating structure in Soc Trang and Ben Tre provinces. (Nguyen et al., 2017 and Tran, 2013.) However, this method was more suitable for crop research where is necessary to prove the correlation between crop structure and salinity for zoning the corresponding salinity, or to have a specific saltwater intrusion scenario to assess the effect.

In the study of Nguyen Quoc Hau et al. (2017), the influence of saline intrusion and the factors of socio-economic conditions on the status of agricultural land use were assessed, thereby proposing suitable solutions for land use. The study used the interpolation method, from salinity monitoring points, to create a salinity intrusion map of Vung Liem district, Vinh Long province. The study shows that the Kriging interpolation algorithm has the potential to be used in estimating areas at risk of saline intrusion, based on geographical coordinates and salinity values at the monitoring points (with reliability of 95%). Because of its simplicity of implementation (fewer input data and low cost) and high accuracy, this method was appropriate for assessing saline intrusion in general studies.

7.2 Weaknesses of the research method

The method used in this study cannot take into account additional factors on salinity prevention structures, for example, sluice gates, water retention and discharge dams and salinity prevention forests. In fact, there are many other factors that influence saltwater intrusion (not simply the spatial correlation between the salinity measurement points), such as precipitation, evaporation, soil moisture, land use structure, river mouth position towards the sea, upstream of Mekong River, topography, meteorological and various socio-economic factors. This may lead to errors in interpolation results compared with reality.

In addition, the interpolation results were based on the average of the highest salinity for the whole dry season 2019-2020, and the intrusion had different intensity in different periods, so the results may differ from reality and forecast. Many measures have been taken in the Mekong Delta to prevent salinity intrusion from reaching the mainland after learning from past natural disasters. Therefore, this interpolation method can produce results with higher values than they are in reality.

The method required a significant number of salinity measuring points to increase the accuracy of the results. It was necessary to have a sequence of data that was accurate and correlated with each other in terms of spatial location to produce a reliable result. In order to obtain data of salinity measurements, a reliable source of measurement from the government was needed. Currently, there are only a few national and provincial agencies in Vietnam that have proper software and facilities to run forecasts of saltwater intrusion and have the rights to manage hydrology and salinity measuring stations and irrigation works for salinity measurement data. Therefore, in order to have adequate salinity data for the computation, a permission from these authorities and agencies is necessary to obtain the measurement data.

In this study, the model did not include all the factors affecting saline intrusion in the Mekong Delta at the present as well as in the future, such as monsoon, demand changes for water in the river basin and flood duration and intensity. The hydraulic and hydrological regime of the Mekong Delta is highly complex; hence, the method cannot give the most accurate results of saline intrusion for the delta, especially under the context of climate change and changes in the upstream of the Mekong River. The method needs to be combined with other factors affecting the saline intrusion of the region, and more scenarios should be established to have a more comprehensive view of the salinity problem in the Mekong Delta region.

The acquired data was based on 2016 statistics, thus there were certain changes in population and agricultural production in the data of 2020. The statistical data was for the whole year, but saline intrusion in the Mekong Delta is cyclical and usually takes place during the dry season, which often does not affect the whole year, so there were some agricultural products that had not been affected during the studied period. In order to increase the accuracy of zoning the impacts on the agricultural production, a detailed and updated map of agricultural land was needed. This study only met the accuracy for assessment in the district level. However, it was sufficient for a general conclusion.

7.3 Recommended solutions for saltwater intrusion

It is necessary to make amendments in a long-term basis to crop structure for the aims of saving water and suiting all water regions (fresh, brackish and saline) of the Mekong Delta. Campaigns can be promoted to fight against drought, exhaustion, and salinity in the Mekong Delta, providing reasonable water storage practices such as small reservoirs, tanks and ponds in villages and communes. The provinces with high salinity in the delta can work with the Can Tho Water Supply Corporation which can supply clean water in large quantities by pipeline to drought and saline areas. In the long run, the government needs to formulate a strategic project that is capable of preventing extreme drought, exhaustion and salinity in focal provinces in the Mekong Delta.

Another solution is to build a system of sluices controlling the saline and fresh flow, suitable for both the output and input on the system of canals and tributaries, turning these into a system of "mobile" reservoirs following the occurrence and fluctuations of tides to control the salinity and retain fresh water. This system works during the peak of the dry season, and in the rainy season, all gates should be opened to allow the normal flow.

Large-scale water reservoirs should not be constructed in the Mekong Delta, since the amount of available land is limited (there is a dense system of rivers and canals). However, the Northern and Central reservoirs in upstream areas have been built for water storage to transfer to drought-salinity areas by canals. The Mekong Delta is low and flat, so a large reservoir with a low elevation will be easier to evaporate and seep through the soil. Besides, the Mekong Delta has thick multi-layered sediment that may cause salinity, acidity and accumulate toxins from production to the reservoirs.

Comparing the salinity situation in 2016 and 2020, the "non-structural" solutions were particularly effective, so it is possible to again consider the "nature-based development" practices. MARD and the provinces need to strongly review the planning of irrigation systems to adjust towards "taking advantage of nature" rather than "overcoming nature". Projects that were effective in the past but no longer suitable for the new approach need to be modified or canceled if necessary.

The evolution of the water source at the end of the rainy season (from September and October) should be annually monitored to plan for the production and storage of fresh water. In the long term, a plan can be implemented to build a fresh water supply system from An Giang - Dong Thap to water plants in the saline areas.

The management of groundwater extraction and exploitation needs to be improved. Saltwater should be truly a resource rather than a risk, and the term "saltwater intrusion" should also be used in a deliberate manner as equitable treatment with saltwater. The concept of controlling salinity instead of preventing salinity needs to be turned into practical actions. Even with saltwater shrimp farming, depending on the period of growth, requires freshwater to dilute to an appropriate salinity. Fresh water is increasingly scarce, but after all, is still a valuable resource for both living and production. Economic sectors based on saline water (or alternating saline and freshwater) are creating more opportunities for people. The government gives priority to preserving water resources for domestic use and supports the improvement of livelihoods to enable people to participate in the value chain effectively.

Continuing to closely monitor the situation and update daily changes in weather, water resources in the upstream of the Mekong River and organizing measurements of salinity in river mouths and inlets of irrigation works can allow to promptly detect changes in saltwater intrusion and estimate appropriate water intake. It is necessary to rationally coordinate the operation of irrigation works to take advantages of water intake when salinity levels are acceptable to increase water storage inland, and urgently close sluice gates when salinity levels are high to ensure the different needs of freshwater and saltwater in localities. The completion of works to prevent drought and saltwater intrusion needs to be accelerated.

Additionally, it is encouraged to modify the structure of crops, especially in areas where water sources are insufficient and that suffer from frequent droughts, water shortages, and saltwater intrusion, to enable diversified agricultural production, meeting the needs of the market, and shifting from focusing on quantity to quality. As rice is the main agricultural product in the region, the locals should balance rice growing areas with water demand.

For aquaculture, the Ministry of Agriculture and Rural Development has stated that it is important to enhance environmental monitoring of farming areas to take prompt responding measures and have appropriate cultivation plans, not starting at the period of drought and saltwater intrusion, increase the use of probiotics to improve water quality to prevent frequent water changes and proactively harvest when reaching commercial size before saltwater intrusion occurs. (Ministry of Agriculture and Rural Development, 2020.)

In the long term, strategic solutions include investing in the installation of automatic salinity monitoring equipment, proactively implementing response measures under the effects of extreme weather. Other potential measures are prioritizing resources for investment in completing the existing irrigation systems, dredging canals and constructing pumping stations to actively control the tides and saltwater intrusion, renovating existing intake gates in the affected areas for a proper operation of fresh water and salt water intake and water drainage, building, upgrading and repairing central water supply works, expanding and extending water supply pipelines, constructing freshwater reservoirs from the system of rivers and dead-end canals and exploiting groundwater in qualified areas.

Given the increasingly complex situation of climate change, it is necessary to take measures to prevent pollution and strengthen international cooperation with countries in the Mekong Commission and China to share mutual benefits in the development of the whole region, in the context of rising sea level and increasingly frequent extreme weather events. At the same time, it is important to limit the construction of hydropower dams on the upstream of the Mekong River basin, avoid the diversion of main flows into sub-branches, and actively increase forest areas to prevent the salinity intrusion.

8 CONCLUSION

In the dry season of 2019-2020, the Vietnam’s Mekong Delta witnessed an exceptional drought and saltwater intrusion. As droughts and saltwater intrusion reoccur almost every year in this region, these natural disasters have led to severe impacts on the livelihood of the locals over time.

This study applied Kriging interpolation technique in geographic information systems (GIS) to analyze and evaluate results from spatial distribution data on salinity. The study established a map of saltwater intrusion status and zoning of the intrusion influence for the dry season 2019-2020 in the Mekong Delta. The effects on the agricultural production were analyzed based on five salinity levels: (1) less than 4 g/l (no effects); (2) from 4 to 8 g/l (slight or minor effects); (3) from 8 to 16 g/l (medium effects); (4) from 16 to 24 g/l (high effects); (5) salinity greater than 24 g/l (very high effects). Salinity decreased gradually with the direction from the coast into the mainland with the greatest concentration in the southernmost area. Approximately half of the agricultural production area and the population in the Mekong Delta were forecast to be at risk of being affected by saline intrusion, with approximately 10% regarded highly affected. This is much less than the proportion of other safer zones. However, this is still significant and can cause damages to the livelihood and the socio-economic situation in the region.

Based on the saline intrusion forecast from the beginning of the dry season, the results of this study presented similar characteristics for saline intrusion in the Mekong Delta. This research method has its own strengths in terms of simplicity and accuracy, so it is possible to apply it to studies related to saltwater intrusion in other areas. Nevertheless, the density of monitoring stations along the Mekong River was still not sufficient to specifically determine the salinity intrusion over time and space. The results can only provide objective information that can be combined with other hydrological models to create early warning systems.

In the complicated phenomenon of climate change and its direct effect, the rising sea level, which causes severe influence on the inland, the accurate and sufficient assessment of salinity intrusion needs aggregating many factors such as topography, climate, hydrology, precipitation, human intervention factors and irrigation works. If the above conditions are met, the evaluation results will be more satisfactory.

Many causes had contributed to the drought and saltwater intrusion of the Mekong Delta, along with extreme climate and weather conditions, from changes in the upstream flow of Mekong River, the water storage capacity at the end of flood season, the evolution of coastal water levels, the situation of water use in the Mekong Delta and the shape of the riverbed and alluvium in the estuary areas to the deficit of precipitation in the early rainy season. It is urgent to propose and implement corrective and mitigation measures, both constructional and non-constructional ones, to minimize the damage and loss from saltwater intrusion.

REFERENCES

Agricultural Atlas of Vietnam. 2020. Web page. Available: http://agro.gov.vn/map3/content/default_E.htm [Accessed 10 May 2020].

Analysis center of the National Agency for Science and Technology Information (Nasati). 2018. Saline water intrusion in the Mekong Delta - What is the deciding factor? Web page. Available: http://nawapi.gov.vn/index.php?option=com_content&view=article&id=4798%3Axam-nhp-mn-nc-di-t-ng-bng-song-cu-long-au-la-yu-t-quyt-nh&catid=70%3Anhim-v-chuyen-mon-ang-thc-hin&Itemid=135&lang=vi [Accessed 1 June 2020].

Asian Disaster Preparedness Center (ADPC). n.d. Droughts in Vietnam. Available: http://adpc.net/fpp/Section6/S6VN01-4-1V.pdf [Accessed 1 June 2020].

Ben Tre Statistical Office. 2011. Statistical Yearbook 2010. Statistical Publishing House.

Center of Survey and Mapping Data. 2019. Administrative map of the Mekong Delta.

Dao, X. H. et al. 2003. Drought and damage mitigation measures. Hanoi Agriculture Publishing House.

Disaster Management Policy and Technology Center. 2015. Basic knowledge (drought, salinity intrusion). Web page. Available: http://dmc.gov.vn/kien-thuc-co-ban-pt32.html?lang=vi-VN [Accessed 1 June 2020].

Disaster Management Policy and Technology Center. 2016. Report on drought, salinity intrusion situation and coping solutions. Web page. Available: http://dmc.gov.vn/Uploads/Thong%20tin%20Thien%20tai%20-%20Disaster%20Information/2016/03.2016/Han%20han/bao%20cao%20han%20vs%20xnm.pdf?lang=vi-VN [Accessed 1 June 2020].

General Statistics Office of Vietnam (GSO). 2020. Statistics. Web page. Available: https://www.gso.gov.vn/Default_en.aspx?tabid=766 [Accessed 15 May 2020].

Humanitarian OpenStreetMap Team (HOT). 2020. Web page. Available: https://data.humdata.org/organization/hot [Accessed 15 May 2020].

Meteorology and Hydrology Station of the South Central region. 2014. Drought. Web page. Available: http://kttvntb.gov.vn/Doc.aspx?d=286&f=29 [Accessed 1 June 2020].

Ministry of Agriculture and Rural Development. 2020. Saltwater Intrusion. Web page. Available: https://www.mard.gov.vn/Pages/ket-qua-tim-kiem.aspx?keyword=%20x%C3%A2m%20nh%E1%BA%ADp%20m%E1%BA%B7n&p=1 [Accessed 15 May 2020].

Ministry of Foreign Affairs. 2020. World Water Day and historic drought and salinity in the Mekong Delta. Web page. Available: https://baoquocte.vn/ngay-nuoc-the-gioi-va-han-man-lich-su-o-dong-bang-song-cuu-long-112016.html [Accessed 15 May 2020].

Ministry of Natural Resources and Environment (MONRE). 2019. Meteorological and hydrological experts analyze the situation of drought and saltwater intrusion in the dry season 2019-2020. Web page. Available: http://www.monre.gov.vn/Pages/chuyen-gia-khi-tuong-thuy-van-phan-tich-tinh-hinh-han-han,-xam-nhap-man-mua-kho-2019-2020.aspx [Accessed 1 June 2020].

Ministry of Natural Resources and Environment (MONRE). 2020. Web page. Available: https://monre.gov.vn/English [Accessed 15 May 2020].

Nguyen, V. H. 2011. Drought: Causes, harms and prevention measures.

Nguyen, N. V., Le, V. T. & Tran, T. V. 2018. Evaluating salinity intrusion in estuaries using remote sensing data integrated in-situ observation. Ho Chi Minh City University of Technology.

Nguyen, Q. H., Cao, T. Q., Le, V. K., Vo, Q. M. & Vo, T. P. 2017. Evaluating effects of saline intrusion and socio-economic factors on agricultural production in Vung Liem district, Vinh Long province. Journal of Science Can Tho University (Environment 2017), 64-70. https://doi.org/10.22144/ctu.jsi.2017.031.

Nguyen, T. H. D., Danh, H. & Nguyen, T. C. 2017. Impact of saline intrusion as a result of climate change on rice cultivation in Soc Trang province. Journal of Science Can Tho University (Environment 2017), 137-143. https://doi.org/10.22144/ctu.jsi.2017.062.

Nguyen, T. K. O. 2014. Application of GIS and interpolation algorithm to evaluate air quality in Dong Nai province. Available: http://gis.hcmuaf.edu.vn/data/file/KhoaLuanTotNghiep_DH10GI/DH10GE_Nguyen_Thi_Kim_Oanh.pdf [Accessed 1 June 2020].

Nguyen, V. T. et al. 2007. Using standardized precipitation index to forecast meteorological drought. Institute of Hydrometeorology and Environment Science.

Nguyen, V. T. 2019. Drought, record salinity intrusion, does the Mekong Delta lack water for domestic use and production? The General Department of Water Resources (MARD). Web page. Available: https://tuoitre.vn/han-han-xam-nhap-man-ky-luc-dbscl-co-thieu-nuoc-sinh-hoat-va-san-xuat-20191219194428876.htm [Accessed 1 June 2020].

Phung, V. P. & Nguyen, T. T. 2018. Study of Tectonic Structures and Recent Geodynamics of the Mekong Delta in order to adapt to and to reduce natural hazards in condition of sea-level rising. Vietnam Academy of Science and Technology.

The Database of Global Administrative Areas (GADM). 2020. Maps. Web page. Available: https://gadm.org/maps.html [Accessed 15 May 2020].

The Southern Institute of Water Resources Research (SIWRR). 2019. Report on water source, salinity intrusion forecast in the dry season of 2019-2020 and proposing solutions for the Mekong Delta. Available: http://www.siwrr.org.vn/docs/2018/files/VKHTLMN_DB_man_nguonnuoc_DBSCL_Ngay30_11_2019.pdf [Accessed 1 June 2020].

The Water Resources Directorate. 2016. Causes of increased saline intrusion in the Mekong Delta and management solutions. Web page. Available: http://www.tongcucthuyloi.gov.vn/Tin-tuc-Su-kien/Tin-tuc-su-kien-tong-hop/catid/12/item/2671/nguyen-nhan-xam-nhap-man-tang-cao-o-dong-bang-song-cuu-long-and-phase-phap-quan-ly [Accessed 1 June 2020].

Tran, Q. D., Nguyen, H. T. & Likitdecharote, K. 2012. Modeling the influence of river discharge and sea level rise on salinity intrusion in Mekong Delta. 35. 685-701.

Tran, T. P. D. 2013. Application of MODIS remote sensing images to partition salinity intrusion in Ben Tre province in 2012. Available: http://gis.hcmuaf.edu.vn/data/file/KhoaLuanTotNghiep_DH09GI/DH09GI_Tran_Thi_Phuong_Dung.pdf [Accessed 8 June 2020].

Tran, T., Nguyen, V. T., Ngo, S. G. & Hoang, M. T. 2008. Mapping of drought and domestic water insufficiency in the South Central and Central Highlands. Institute of Meteorology, Hydrology and Climate Change.

Vietnam Academy of Agriculture Sciences. 2020. The drought and salinity intrusion in the Mekong Delta exceeded the 2016 record. Web page. Available: http://www.vaas.org.vn/han-man-o-dbscl-vuot-muc-ky-luc-nam-2016-a19193.html [Accessed 15 May 2020].

Vietnam Disaster Management Authority. 2020. Assessment of drought and saltwater intrusion; Causes and forecasts of drought, salinity intrusion in the Mekong Delta from an expert perspective. Web page. Available: http://phongchongthientai.mard.gov.vn/Pages/ts-to-van-truong-tra-loi-bao-phap-luat-va-truyen-hinh-ve-tinh-trang-han-han-xam-nhap-man--.aspx [Accessed 15 May 2020].

Vietnam Disaster Management Authority. 2020. Synthesis Report on Drought, Salinity Intrusion in the Southern Region 2019 - 2020 (Updated by 02/03/2020). Available: http://phongchongthientai.mard.gov.vn/Pages/bao-cao-tong-hop-tinh-hinh-han-han-xam-nhap-man-khu-vuc-mien-nam-2019--2020.aspx [Accessed 1 June 2020].

Vietnam Ministry of Education and Training (MOET). 2014. Geography. Workbook. 9th edition. 125-134.

Vietnam National Center for Hydro-Meteorological Forecasting. 2020. Saltwater intrusion. Web page. Available: https://nchmf.gov.vn/KttvsiteE/vi-VN/1/xam-nhap-man-20-18.html [Accessed 10 May 2020].

Wilhite, D. A. 2000. Drought as a natural hazard: concepts and definitions: In: Wilhite D. A. Wilhite (ed.). Drought: A Global Assessment, Natural Hazards and Disasters. Series Routledge Publishers, New York, 3-18.

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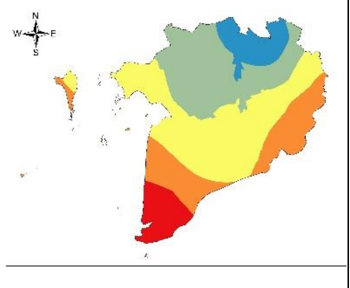
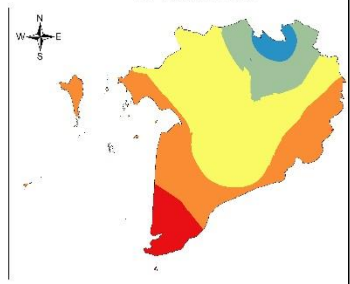
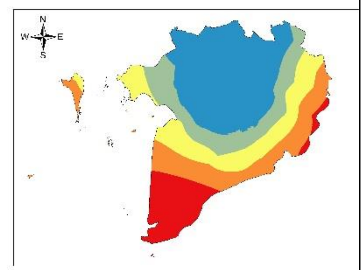
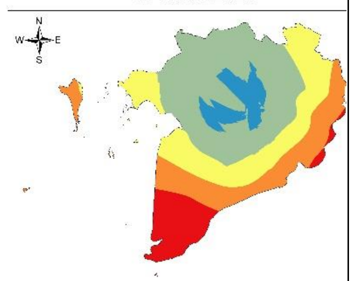
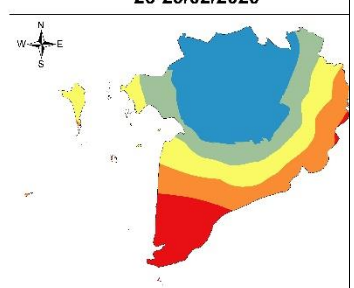
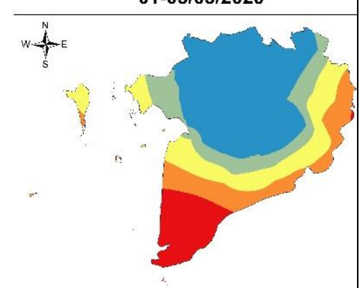
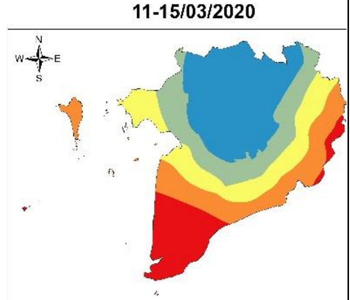
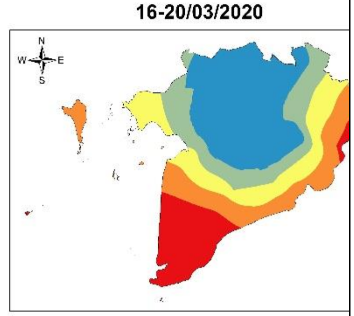
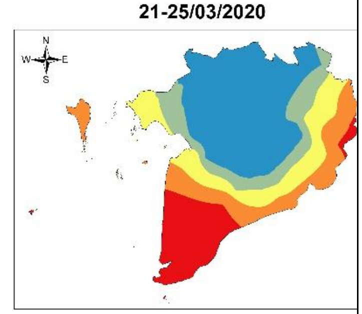
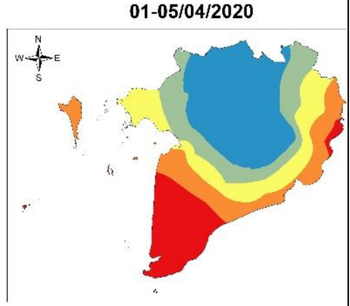
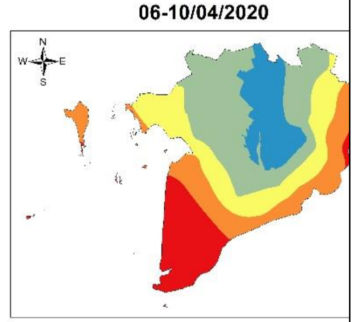
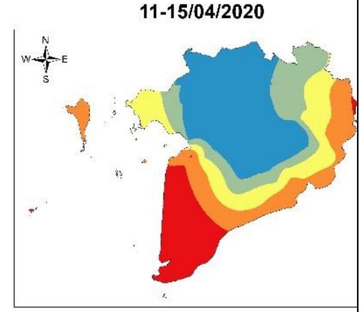
Table 6. Salinity intrusion from 01/02/2020 to 30/04/2020

01-10/02/2020 	**11-15/02/2020** 	**16-20/02/2020** 
21-25/02/2020 	**26-29/02/2020** 	**01-05/03/2020** 
11-15/03/2020 	**16-20/03/2020** 	**21-25/03/2020** 
01-05/04/2020 	**06-10/04/2020** 	**11-15/04/2020** 

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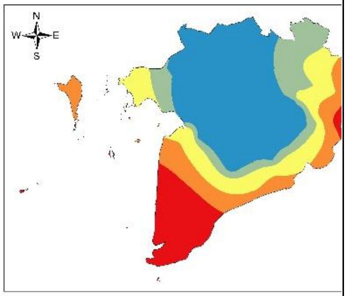	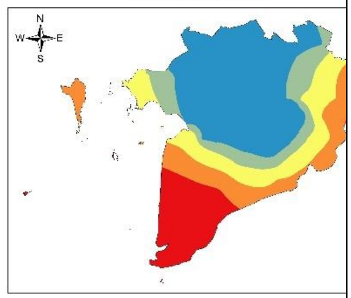	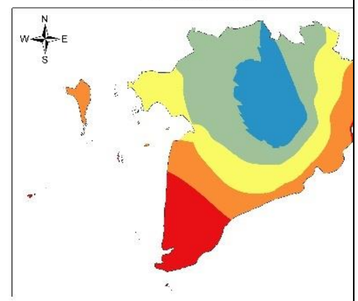
	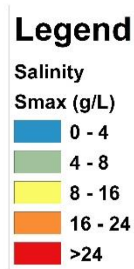	

Table 7. The average salinity at stations from 12/2019 to 04/2020

ID	Station	River	Province	Average
1	An Định	Tiền	Tiền Giang	6.8737
2	An Lạc Tây	Hậu	Sóc Trăng	1.5692
3	An Ninh	Cái Bé	Kiên Giang	16.2600
4	An Thuận	Hàm Luông	Bến Tre	26.7957
5	Bến Lức	Vàm Cỏ Đông	Long An	7.6273
6	Bến Trại	Cổ Chiên	Bến Tre	19.3600
7	Bình Đại	Cửa Đại	Bến Tre	26.6733
8	Cà Mau	Gành Hào	Cà Mau	28.7522
9	Cẩm Sơn	Cổ Chiên	Bến Tre	5.9000
10	Cầu Nổi	Vàm cỏ	Long An	18.3857
11	Cầu Quan	Hậu	Trà Vinh	8.4000
12	Chợ Lách	Cổ Chiên	Bến Tre	5.8000
13	Đại Ngãi	Hậu	Sóc Trăng	7.4591
14	Đồng Tâm	Tiền	Tiền Giang	5.6467
15	Đức Mỹ	Cổ Chiên	Trà Vinh	2.8615
16	Đường Đức	Hậu	Trà Vinh	3.8923
17	Gành Hào	Gành Hào	Bạc Liêu	27.5385
18	Gò Quao	Cái Lớn	Kiên Giang	8.1391
19	Hòa Bình	Cửa Tiểu	Tiền Giang	12.1500
20	Hưng Mỹ	Cổ Chiên	Trà Vinh	13.9667
21	Hương Mỹ	Cổ Chiên	Bến Tre	7.6267
22	Láng Thé	Láng Thé	Trà Vinh	5.3615
23	Lộc Thuận	Cửa Đại	Bến Tre	15.5400
24	Long Đại	Đồng Nai	Tp.HCM	1.8286
25	Long Phú	Hậu	Sóc Trăng	15.9267
26	Long Thạnh	Cái Bé	Kiên Giang	1.0857
27	Long Toàn	K.Quan Chánh Bố	Trà Vinh	22.6154

28	Lý Nhân	Nhà Bè	Tp.HCM	24.5923
29	Mỹ Hóa	Hàm Luông	Bến Tre	15.9692
30	Mỹ Tho	Tiền	Tiền Giang	5.7421
31	Ngã 3 Cát Lái	Nhà Bè	Tp.HCM	6.9000
32	Ngã Năm	K.Phụng Hiệp	Sóc Trăng	2.4077
33	Nhà Bè	Đồng Điền	Tp.HCM	13.0250
34	Nhuận Phú Tân	Cổ Chiên	Bến Tre	1.3000
35	Phú Khánh	Hàm Luông	Bến Tre	13.1875
36	Phú Túc	Ba Lai	Bến Tre	4.7923
37	Phước Long	K.Phụng Hiệp	Bạc Liêu	15.7353
38	Quới Sơn	Mê Kông	Bến Tre	7.3333
39	Rạch Giá	Kiên	Kiên Giang	0.7429
40	Sóc Trăng	K. Maspero	Sóc Trăng	4.9533
41	Sơn Đốc	Hàm Luông	Bến Tre	24.0867
42	Sông Đốc	Sông Đốc	Cà Mau	36.7773
43	Tân An	Vàm Cỏ Tây	Long An	7.2579
44	Tân Thiềng	Cổ Chiên	Bến Tre	0.4000
45	Thạnh Phú	K. Như Gia	Sóc Trăng	10.6667
46	Thành Thới Thuận	Mỹ Thạnh	Sóc Trăng	21.2231
47	Trà Kha	Hậu	Trà Vinh	17.6400
48	Trà Vinh	Cổ Chiên	Trà Vinh	7.0261
49	Trần Đề	Hậu	Sóc Trăng	20.1273
50	Tuyên Nhơn	Vàm Cỏ Tây	Long An	3.3143
51	Vàm Kênh	Cửa Tiểu	Tiền Giang	23.9867
52	Vàm Mơn	Hàm Luông	Bến Tre	10.3444
53	Xẻo Rô	Cái Lớn	Kiên Giang	17.6913
54	Xuân Khánh	Vàm Cỏ Đông	Long An	2.4429

Estimated location of the salinity levels in the Mekong Delta

(1) Area with salinity less than 4 g/l was 1 357 100 ha (accounting for 33.71%), including districts in provinces of An Giang (An Phu, Cho Moi, Chau Doc, Chau Phu, Chau Thanh, Long Xuyen, Phu Tan, Tan Chau, Thoai Son), Can Tho (Binh Thuy, Co Do, Cai Rang, Ninh Kieu, O Mon, Phong Dien, Thot Not, Thoi Lai, Vinh Thanh), Dong Thap (Cao Lanh, Chau Thanh, Hong Ngu, Lap Vo, Lai Vung, Sa Dec, Tam Nong, Tan Hong, Thanh Binh, Thap Muoi), Hau Giang (Chau Thanh, Chau Thanh A, Nga Bay, Phung Hiep, Vi Thuy), Kien Giang (Giong Rieng, Tan Hiep), Long An (Duc Hue, Kien Tuong, Moc Hoa, Tan Hung, Tan Thanh, Thanh Hoa, Vinh Hung), Soc Trang (Ke Sach), Tien Giang (Cai Be, Cai Lay), Vinh Long (Binh Minh, Binh Tan, Long Ho, Mang Thit, Tam Binh, Tra On, Vinh Long, Vung Liem).

(2) Area with salinity ranges from 4 to 8 g/l was 748 650 ha (accounting for 18.60%), including districts in provinces of An Giang (Tinh Bien, Tri Ton), Ben Tre (Cho Lach, Chau Thanh, Mo Cay Bac), Hau Giang (Long My, Vi Thanh), Kien Giang (Chau Thanh, Go Quao, Hon Dat, Rach Gia), Long An (Tan An, Ben Luc, Duc Hoa, Thu Thua), Soc Trang (Chau Thanh, My Tu, Nga Nam), Tien Giang (Cai Lay, Chau Thanh, My Tho, Tan Phuoc), Tra Vinh (Cau Ke, Cang Long).

(3) Area with salinity ranges from 8 to 16 g/l was 751 200 ha (accounting for 18.66%), including districts in provinces of Bac Lieu (Hong Dan, Phuoc Long, Vinh Loi), Ben Tre (Mo Cay Nam, Giong Trom, Ben Tre), Kien Giang (An Bien, Giang Thanh, Ha Tien, Kien Hai, Kien Luong, U Minh Thuong, Vinh Thuan), Long An (Tan Tru, Chau Thanh, Can Duoc, Can Giuoc), Soc Trang (Cu Lao Dung, Thanh Tri, My Xuyen, Soc Trang, Long Phu), Trà Vinh (Tieu Can, Chau Thanh, Tra Vinh, Tra Cu), Tien Giang (Cho Gao, Go Cong Tay).

(4) Area with salinity ranges from 16 to 24 g/l was 693 850 ha (accounting for 17.24%), including districts in provinces of Bac Lieu (Gia Rai, Hoa Binh, Bac Lieu), Ben Tre (Thanh Phu, Ba Tri, Binh Dai), Ca Mau (Thoi Binh), Kiên Giang (An Minh, Phu Quoc), Soc Trang (Vinh Chau, Tran De), Tien Giang (Tan Phu Dong, Go Cong Dong, Go Cong), Tra Vinh (Cau Ngang, Duyen Hai).

(5) Area with salinity greater than 24 g/l was 474 900 ha (accounting for 11.80%), including most districts and cities in Ca Mau province (Ngoc Hien, Nam Can, Phu Tan, Cai Nuoc, Dam Doi, Tran Van Thoi, U Minh, Ca Mau), Dong Hai district (Bac Lieu).