Agriculture in Viet Nam under the impact of climate change

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Chapter 4

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Abstract

Over the past 30 years, strong agricultural growth has changed the socio-economic status of Viet Nam: improving food security, boosting agricultural exports, and creating livelihoods for people. However, the agricultural sector has already been impacted by climate change, and projections for the next few decades indicate that the climate warming trends and anthropogenic pressures are likely to be accelerated.

In this chapter, we examine evolution in crop yields in the past decades, and its predicted evolution in the future. The results vary widely between crops, agro-ecological zones and climate scenarios, but most findings concur on the decline of crop yields in the 2030–2050 horizon. On the other hand, the habitat suitability for rice and other major crops will undergo drastic changes. We find that without adaptation, the risks of increasing saline intrusion, and that of permanent inundation due to sea level rise, will significantly reduce (up to 50% by 2050) the land suitable for rice cultivation in the Mekong delta . However, these two main threats to rice cultivation are accentuated by anthropogenic pressures (ground water pumping and sand mining), which require specific policies to be mitigated.

Among the adaptation practices, we highlight practices that mitigate the greenhouse gas emissions from agriculture. In particular, the Alternate Wetting and Drying irrigation of rice fields is a single mitigation practice that can reduce the methane emissions from rice fields in Viet Nam by 40%.

However, to derive adaptation and mitigation measures for the agriculture sector over the coming decades will require assessments against a background of wider environmental, economic and social evolutions.

Tóm tắt

Trong 30 năm qua, tăng trưởng nông nghiệp mạnh mẽ đã làm thay đổi tình trạng kinh tế xã hội của Việt Nam: cải thiện an ninh lương thực, đẩy mạnh xuất khẩu nông sản, tạo sinh kế cho người dân. Tuy nhiên, ngành nông nghiệp đã bị tác động bởi biến đổi khí hậu và các dự báo trong vài thập kỷ tới chỉ ra rằng xu hướng nóng lên của khí hậu và áp lực do con người gây ra sẽ được đẩy nhanh.

Trong chương này, chúng tôi xem xét sự tiến hóa về năng suất cây trồng trong những thập kỷ qua và dự đoán sự tiến hóa trong tương lai. Các kết quả thu được rất khác nhau giữa các loại cây trồng, vùng sinh thái nông nghiệp và các kịch bản khí hậu, nhưng hầu hết đều đồng tình về sự suy giảm năng suất cây trồng trong giai đoạn tương lai 2030-2050. Mặt khác, sự thích hợp về môi trường sống của lúa và các cây trồng khác sẽ có những thay đổi mạnh mẽ. Chúng tôi nhận thấy rằng nếu không có sự thích ứng, nguy cơ gia tăng xâm nhập mặn và ngập lụt dai dẳng do nước biển dâng sẽ giảm đáng kể (lên đến 50% vào năm 2050) diện tích đất thích hợp trồng lúa ở Đồng bằng sông Cửu Long. Tuy nhiên, hai mối đe dọa chính đối với canh tác lúa được nhấn mạnh bởi áp lực con người (bơm nước ngầm và khai thác cát), đòi hỏi các chính sách hiệu quả để được giảm thiểu.

Trong số các thực hành thích ứng, chúng tôi nêu bật các thực hành giúp giảm nhẹ phát thải khí nhà kính từ nông nghiệp. Đặc biệt, việc tưới nước và làm khô xen kẽ trên ruộng lúa là một phương pháp giảm thiểu duy nhất có thể giảm 40% lượng khí mê-tan phát thải từ ruộng lúa ở Việt Nam.

Tuy nhiên, để đưa ra các biện pháp thích ứng và giảm thiểu cho ngành nông nghiệp trong những thập kỷ tới sẽ đòi hỏi những đánh giá dựa trên nền tảng của những tiến triển về môi trường, kinh tế và xã hội rộng lớn hơn.

Résumé

Au cours des 30 dernières années, la forte croissance agricole a changé le statut socio-économique du Viet Nam : amélioration de la sécurité alimentaire, augmentation des exportations agricoles et création de moyens de subsistance pour les populations. Cependant, le secteur agricole a déjà été touché par le changement climatique, et les projections pour les prochaines décennies indiquent que les tendances au réchauffement climatique et les pressions anthropiques sont susceptibles de s'accélérer.

Dans ce chapitre, nous examinons l'évolution des rendements des cultures au cours des dernières décennies et l'évolution prévue dans le futur. Les résultats varient considérablement entre les cultures, les zones agro-écologiques et les scénarios climatiques, mais la plupart des résultats concordent sur la baisse des rendements des cultures à l'horizon 2030–2050. D'un autre côté, les terres adaptées à la culture du riz et celles des autres cultures subiront des changements drastiques. Nous constatons que sans adaptation, les risques d'augmentation des intrusions salines, et celui d'inondations permanentes dues à l'élévation du niveau de la mer réduiront considérablement (jusqu'à 50% d'ici 2050) les terres propices à la riziculture dans le delta du Mékong. Cependant, ces deux principales menaces pesant sur la riziculture sont accentuées par les pressions anthropiques (pompage des nappes phréatiques et extraction de sable) dont la réduction nécessitera des politiques spécifiques..

Parmi les pratiques d'adaptation, nous soulignons les pratiques qui atténuent les émissions de gaz à effet de serre provenant de l'agriculture. En particulier, l'irrigation alternée des rizières est une pratique d'atténuation unique qui permet de réduire de 40% les émissions de méthane des rizières au Viet Nam.

Cependant, pour dériver des mesures d'adaptation et d'atténuation pour le secteur agricole au cours des prochaines décennies, il faudra des évaluations dans un contexte d'évolutions environnementales, économiques et sociales plus larges.

1. Viet Nam agriculture Past and present

1.1 Introduction

The agriculture sector plays a crucial role in Viet Nam's economy and society. In 2020, agriculture, forestry and fishing accounted for 14.85% of the country's GDP. The agriculture sector accounted for 33.06% of total employment in Viet Nam, with approximately 17.72 million people employed [Viet Nam General Statistics Office (GSO), 2021].

Viet Nam covers a total area of 331,698 km^2 and stretches over 15 latitudes (from 8° 35' N to 23°22' N), with a population of over 97.5 million [GS0, 2021]. The climate is diverse from north to south, divided into three distinct zones, including a subtropical humid climate in the North, a tropical monsoon climate in Central and South-Central regions, and tropical savannah in the Central and Southern regions. The north has four seasons, the south has a rainy season and a dry season. Annual rainfall ranges from 1,200 mm to 3,000 mm. The country is endowed with terrain and climate favourable to agriculture, including rice, coffee, rubber, tea, pepper, soybeans, cashews, sugar cane, peanut, banana, and many other agricultural products.

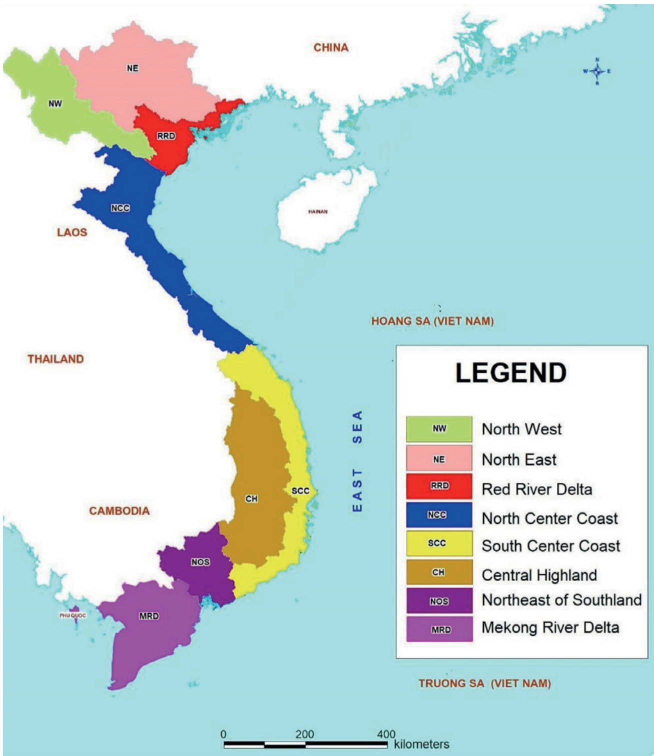
Viet Nam is divided into eight agro-ecological regions, according to climate and topography: the North West, the North East, the Red River Delta, the North Central Coast, the South Central Coast, the Central Highlands and the South East and the Mekong River Delta [Figure 4.1].

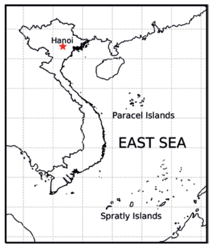
Agricultural production is specialized according to the characteristics of agro-ecological regions. While rice production is concentrated in two delta regions (Red River Delta and Mekong River Delta), the majority of cash crops are produced in the Central Highlands and the Southeast. The Northeast and Northwest are mountainous areas, where agricultural production mainly serves the needs of households, except in areas with favorable conditions for the development of industrial crops such as tea and rubber. Only about 15% of the land in the north is arable, concentrated in the lowland areas of the Red River Delta. In the centre, agriculture is distributed along the coast. Agriculture in the southern region is dominated by the Mekong Delta, one of the great rice-producing regions of the world.

Rice, the main staple of the Vietnamese diet, occupies 94% of arable land, is cultivated in all regions, and is the top crop in terms of planted area in 5 of the regions. The Mekong River Delta and the Red River Delta represent 54.47% and 24.80% of the national rice-planted area. In 2020, rice production amounted to approximately 42.7 million tonnes, making Viet Nam the 5th world rice producing country and 2nd rice exporting country [GSO, 2021].

The other crops with the largest planted areas vary among regions. In the Northern Midlands and Mountains, maize, fruit trees and perennial industrial plants dominate. In the North Central and South central coast regions, maize and cassava are respectively the second crop after paddy. The Highlands region is stand out for the prevailing perennial industrial plants (coffee, tea, etc.), far above the area planted with paddy, maize and cassava. In the South East region, perennial industrial plants (rubber, pepper, etc.) and fruit trees dominate. Among perennial industrial crops,

[Figure 4.1]
Viet Nam main agro-ecological zones





source: IMHEN

coffee had the highest production, amounting in 2020 to over 1.74 million tonnes, making Viet Nam one of the leading coffee producing and exporting countries worldwide [Statista Research department, 2021].

1.2 Past evolution of crop yield and crop planted area in Viet Nam

Climate change impacts agricultural production in two components: crop area and crop yield. Crop area can be reduced (or extended) following changes in habitat suitability under climate effects; whereas crop yield (or crop productibility) is affected by changes in seasonal patterns of temperature, precipitation, and by adverse phenomena such as drought, inundation, saline intrusion, cold and hot spells, etc. However, factors other than climate include socio-economic and political factors contributing to changes of crop area, and technological advances in crop management contributing to changes in crop yield. For these reasons, studies using past survey data to relate changes in a single climate indicator (such as temperature) to changes in crop production can be severely biased.

As stated above, yield — the mass of harvested crop product in a specific area — is influenced by several factors. These factors are grouped into three basic categories known as technological (agricultural practices, managerial decisions, etc.), environmental (climatic condition, soil fertility, topography, water quality, etc.), and biological (seed varieties, diseases, insects, pests, etc.). It is worth noting that: a) the definition of 'crop yield' given by the FAO is 'harvested production per unit of harvested area for crop products'; and b) in most of cases, yield data are not measured, but obtained by dividing production data by data on harvested or planted area.

On a global scale, the yields of major crop types have had an increasing trend in the last decades. While yield-increasing trends have remained linear for some crops and countries, a yield plateau is evident in several cases. For example, yields are plateauing in some of the world's most important cereal-producing countries, such as wheat in Europe or rice in Korea and China [Van Ittersum and Cassman, 2013]. One hypothesis is that the yield stabilizes when it reaches the potential yield, which represents a biophysical ceiling on the attainable yield at a given location, or at a regional and national level [Tran *et al.*, 1997]. Yield potential is defined as the yield an adapted crop cultivar can achieve when crop management eliminates all limitations to crop growth and yield from nutrient deficiencies, water deficit or surplus, salinity, weeds, insect pests and pathogens.

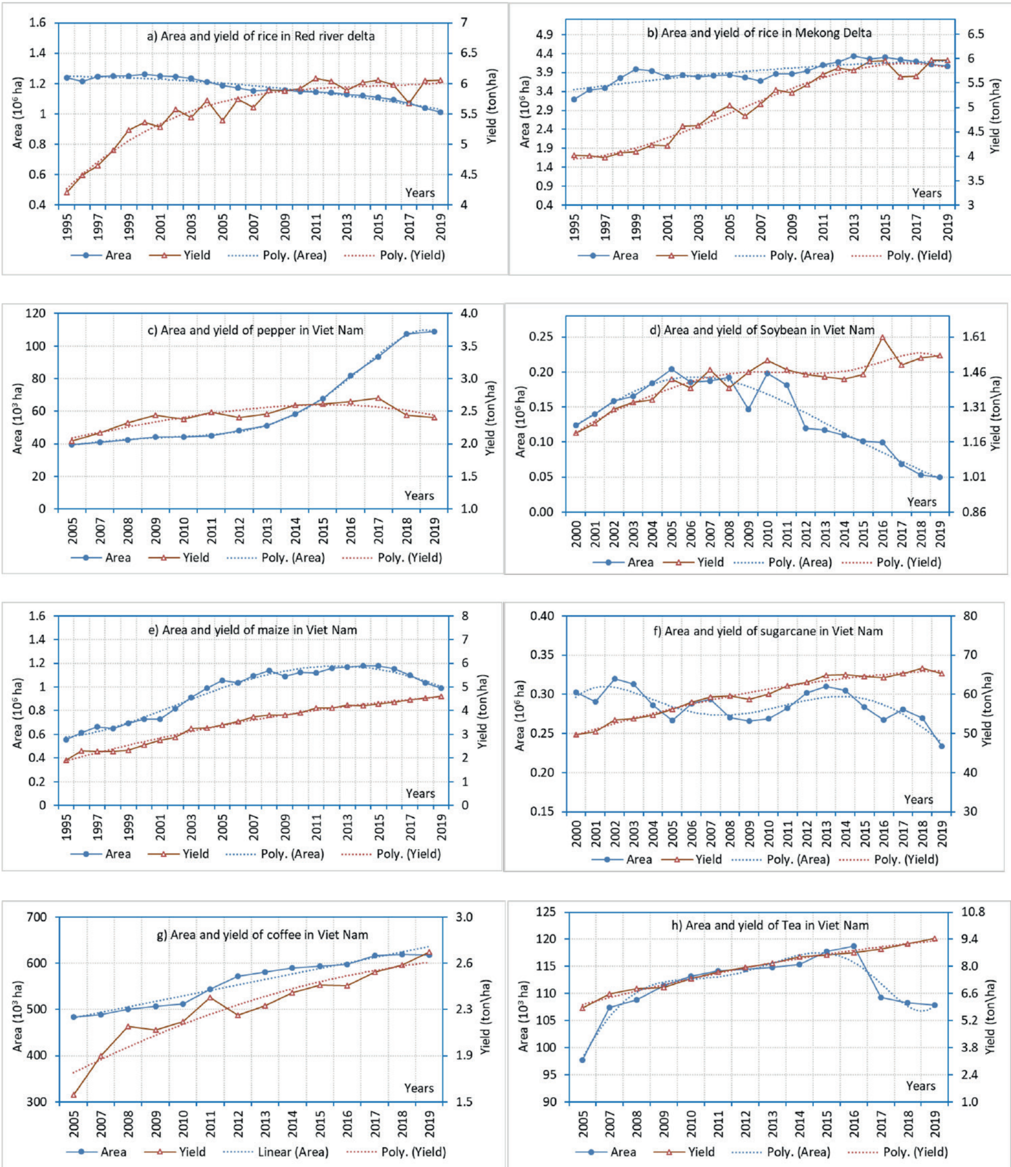
Until the potential yield of a specific crop in a given environment is reached, the crop yield could have a steadily increasing trend owing to technological improvements, despite annual fluctuations due to climate effects. Beyond the stage where potential yield has been reached, variations in rainfall, temperature, and extreme weather events are the major causes of variations in crop yield. This is the case of agricultural production in many regions in the world, in America or in Europe for example [Shauberger *et al.*, 2018]. In addition, in the long run, intensive agricultural production characterized by the overuse of fertilizers and chemicals can lead to a decrease in crop productivity due to a decline in soil health and environmental damage, in the end making the land unsuitable for crop cultivation. In Viet Nam, the pressure to increase crop production has, since the early 1990s, resulted in both the expansion of land area dedicated to agriculture and the improvement of crop yields. The latter has been through intensification of crop management based on practices such as irrigation, use of large quantities of inputs like inorganic fertilizers and synthetic chemicals for pest and weed control, and increase in the number of annual crops per year on the same field. A wide range of technological innovations in agriculture, including genetic improvement of varieties, fertilizer technology, pesticides, farm machinery, agronomic and management practices, have been implemented to enhance crop productivity

Figure 4.2 shows the evolution of annual planted area and yield for paddy rice in the Red River Delta and Mekong River Delta, and for some major crop types (maize, soybean, sugar cane, pepper, coffee and tea) in Viet Nam. The graphs are based on statistical data provided by General Statistics Office since 1995, 2000 or 2005, depending on the crop type.

In Figure 4.2 a,b,c and d, the yield of paddy rice, pepper and soybean show an increasing trend from 1995, followed by a plateau or decrease in the yield, observed after different periods: 2009 for rice in the Red River Delta, 2014 for rice in the Mekong River Delta, 2015 for pepper, 2009 for soybean. For these crops, it could be interpreted that the potential yield has been reached, and that annual fluctua-

[Figure 4.2]

Evolution of annual planted area (blue) and yield (red) of major crop types in Viet Nam



Evolution of annual planted area (blue) and yield (red) for rice crop a) rice in Red River delta, b) rice in Mekong River delta, and for the main crop types in Viet Nam: c) pepper, d) soy bean e) maize, f) sugarcane, g) coffee, h) tea.

tions in the yields could be attributable to climate effects, as for example in 2016–2017, after the El Niño year.

On the other hand, the yields of maize, sugar cane, tea, and coffee show a continuous increase over the period [Figure 4.2.e,f,g,h]. A first interpretation is that management practices — such as irrigation, use of high-yield varieties, and use of large quantities of inputs — are still being optimised. For these crop types, at the country scale, the impacts of cultural practices appear to dominate any climate change effects up to now.

For crop planted area, the past evolution reflects decisions by farmers and communities, following national policies — through land use planning [*e.g.* Government of Viet Nam, 2019] — and also individual adaptation practices, to cope with variations in product demand in both the domestic market and international trade. It is important to note that the driver of change in crop area is not only crop production, but also overall crop grower revenue, which includes income after expenses from production and is calculated by substracting farm expenses from gross farm income. For the production output per ha, the quality of crop product and its market value are therefore very important factors. The increase in crop planted area observed for pepper and coffee may denote that farmer revenue is still increasing; whereas the decrease of rice-planted area in the Red River Delta may indicate market competition with other crop types and other land use (*e.g.* urban expansion: the Red River Delta has a population density of 1,064 people per km^2, compared to 423 people per km^2 in the Mekong River Delta). Similarly, the abrupt decrease in tea-planted area in 2017 may denote that less farmers are willing to invest in tea plantation due to a regular decline in prices, following over-supply on the world market [Doan Ba Thoai *et al.*, 2019]. In 2019, the Food and Agriculture Organisation (FAO) of the United Nations estimated a surplus of about 75,000 tonnes of tea, and this figure is expected to increase to 128,000 tonnes in 2020. Likewise, planted area of maize, soybean, and sugar cane show a decreasing trend after an initial increasing phase.

However, farmers' decisions to change the crop type or land-use type are driven not only by the increase in income, but also by the need to adapt to climate change effects, when habitat suitability for a given crop is reduced by flood, drought, saline intrusion, or hot and cold spells, for example. Hence, the conversion or rotation of rice area into aquaculture in the Mekong Delta coastal provinces can be explained by the higher increasing rate of gross product per ha of aquaculture (mean annual increasing rate from 2012 of 7.2%, as compared to the mean rate of cultivated land of 3.7% (data from GSO 2021), but also by the need to adapt to drought and increased saline intrusions (see Chapter 9 and Chaper 10).

The changes in crop grown area therefore involve a continuous process of adaptation to weather, technology, economic and other influences, and result from a combination of autonomous adaptation (by farmers) alongside planned adaptation, as a consequence of government policy.

For the projections of future crop area, simulations can be made to determine the land area that will become unsuitable for crop growth [*e.g.* in Dang *et al.*, 2020], whereas the evolution of socio-economic and political factors is more difficult to predict. Over the coming decades, changes in diets and consumer preferences (*e.g.* falling demand for rice), market liberalization, and trade (which will expose Viet Nam to higher quality product competition) will all have important effects on the demand for and the supply of agricultural products. The impacts of climate change on crop production have therefore to be assessed against a background of wider economic and social evolutions

1.3 Regional Climate stressors

The effects of climate on agricultural production can be separated into two types: 1] weather shocks, defined as extreme events such as extreme temperatures, floods, droughts and typhoons (or hydro-meteorological disasters), and 2] the long-term effects of changing temperature and precipitation.

Viet Nam is among the countries most vulnerable to climate-related events and climate change. Since the country lies in several eco-climatic regions, the risks are not the same from North to South.

According to the bulletins of Climate forecast and agro-meteorology for Viet Nam published by IMHEN (Viet Nam Institute of Meteorology, Hydrology and Climate Change), the impact of hydro-meteorological disasters on agro-ecological regions in recent years can be summarised as follows (see also Chapter 1 for temperature and precipitation trends over the past decades):

1] The Northeast and Northwest: in this region, the main crop type is rice , with 665.5 thousand ha (T ha), followed by fruit trees (264.7 T ha), and perennial industrial plants (149.8 T ha). Although the average annual temperature has been observed to increase, severe cold and damaging cold events have tended to be longer and more severe. For example, the cold spells in January or February 2008, 2010, 2019, 2021 caused severe losses of transplanted rice, fruit and industrial plants.

2] The Red River Delta: the main crop in the delta is rice (983 T ha), and the second is perennial fruit trees (101 T ha). Like other deltas in the tropical belt, this area often faces floods, landslides, coastal erosion, water shortage, and saltwater intrusion in the dry season. Extreme weather patterns occur more and more and are becoming more complicated and difficult to predict. Rainfall is greatly reduced in the dry season. The annual rainy season tends to start late and to end early, resulting in a decrease in rainfall and runoff. In the coastal area of the Red River Delta in particular, thousands of hectares of rice in the spring crop suffer from drought or from reduction in irrigation water every year, due to reduced rainfall.

3] The North Central Region and South Central Coast: the main crop type is rice (1157 T ha), followed by maize, cassava, fruit trees and industrial plants (each around 100 T ha). Increasing temperature is one of the clear manifestations of climate change in these regions. The average annual rainfall has not changed much, increasing slightly, but with uneven distribution. Heavy rain is concentrated in a short time, and so often causes local flooding and landslides, and drought has increased during the dry season. Although the temperature has increased in winter, severe cold spells have also increased and last longer. The area of rice crops that lacks water at the end of the Summer-Autumn crop is increasing. Over the past 5 years, many reservoirs have been exhausted, and the downstream areas of the rivers are increasingly affected by saltwater intrusion. Floods also occur more frequently, causing many areas of annual crops to be flooded and to have to be replanted, or their yield to be si-

gnificantly reduced. In recent years, farmers in many places have had to convert their rice land to dry crops or rotate crops and intercrop short-term crops, and the rice crop calendar has been readjusted to avoid late drought and early flooding.

4] The Central Highlands: the main crop in the region is perennial industrial plants (1047.7 T ha), rice accounts for 246.8 T ha, followed by maize and cassava, each with about 200 T ha. This region is characterized by extreme climate events and natural disasters, such as floods and flash floods in the rainy season; drought and extreme heat in the dry season. Thunderstorms, tornados and hail occur more and more irregularly. The temperature has increased, annual rainfall has decreased and is distributed less evenly, and the dry season lasts longer. This, together with the reduction of forest area, has severely reduced water resources, causing increased drought, but also causes more floods in the rainy season. Hot weather and drought greatly affect the yield and quality of coffee trees, pepper and fruit trees. The increasing temperature trend also makes pests and diseases develop faster. Farmer adaptation consists in increasing irrigation, and pest and pathogen treatment; the latter may have a detrimental impact on the quality required for exported products.

5] The Southeast Region: the main crop in the region is perennial industrial plants (794.5 T ha), with rice and fruit trees accounting for 260.7 T ha, and 127.4 T ha respectively. The region has a relatively mild climate, with fewer natural disasters than the rest of the country. However, in recent years, rainfall has decreased in the dry season and increased in the rainy season, and many intense rains cause flash floods, landslides, and soil erosion.

6] The Mekong River Delta: this region is considered to be one of the three deltas in the world most vulnerable to climate change and sea level rise (cf. Part 3 of this report). The region's main crop by far is rice (3963.7 T ha), followed by fruit trees (377.7 Tha). The risk of drought and saltwater intrusion often occurs during the Winter-Spring rice crops, particularly in El Niño years. Severe drought years such as 1977–1978, 1997–1998, 2015–2016 and 2019–2020 are all related to El Niño events, which greatly affect production and life in the Mekong Delta. Coastal provinces are strongly affected by saline intrusion from the second half of December to the end of April. Recently, saline intrusions tend to occur earlier, with increased salinity concentrations and duration, and are more invasive in the fields (cf. Chapter 9). In recent years, farmers in many provinces have had to readjust the crop calendar, to rotate rice with short-term crops, or to convert their rice land to aquaculture. It is worth noting that the rate of increase in aquaculture area in the Mekong Delta experienced an important surge after El Ninõ 2015–2016 (mean annual increase of 18.3 T ha in 2016–2019, as compared to 4.25 T ha in 2008–2015).

In summary, diverse impacts of hydro-meteorological disasters on agricultural production have already been observed in agro-ecological regions of Viet Nam. Over the last decades, autonomous adaptation by farmers, and policy interventions to avoid or to attenuate such impacts, have also been observed.

Regarding the effects of long-term changes in climate indicators on crop productivity, reseach has been conducted on the subject; its outcomes will be summarized in the following section.

1.4 Monitoring agriculture with satellite data

To assess the impacts of climate change on crop production in the past and present in Viet Nam, the approach usually adopted has been to use statistical data on crop production, crop yield and crop planted area, provided by General Statistics Office.

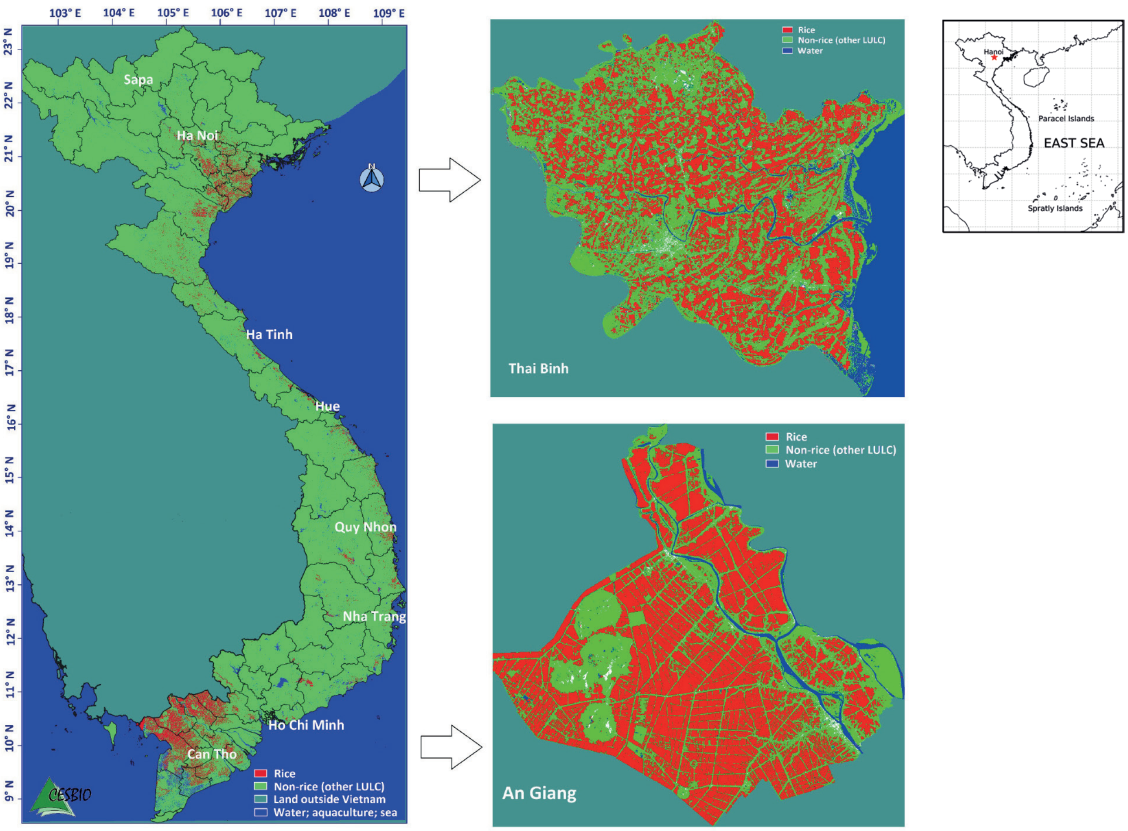
However, understanding the impact of climate change on agriculture requires the dynamic monitoring of crops planted and harvested area, monitoring of crop growth and yield indicators, and determining the crop calendar at a given site. In particular, in crop yield models, the effects of temperature, precipitation, saline intrusion etc. on crop development depend strongly on the crop growth stage. However, because of farmer adaptation to climate change, the crop calendar can vary substantially from the standard ones. For example in the Mekong Delta, the sowing period for the Summer-Autumn crop ranges from March 1 to May 30. But in recent years, sowing dates as late as the second half of June have been observed in many places in the coastal provinces of Ben Tre, Tra Vinh, Kien Giang, Soc Trang, Bac Lieu, Ca Mau, in order to avoid saline intrusions. Similarly, brief episodes of unusually high or low temperature can affect grain yield, especially if they occur at the reproductive phenological stage, which is most sensitive to temperature, but adaptations in management can avoid or attenuate some of the negative impacts.

All these monitoring requirements are well suited to the capacities of Earth Observation techniques. In addition, multi-annual observations by satellites can provide information on adaptation measures adopted by farmers, or or decided by policy regulations, such as changes in crop calendar, cropping density (number of crops per year), changes in crop types or conversion to other land use, for example.

An observation system providing a synoptic view (*e.g.* for the entire Mekong Delta), combined with 10 m–20 m pixel size for observation at field level and a weekly repeated frequency, would be optimal. In addition, for Viet Nam as well as for other tropical countries, only radar systems can provide systematic observations, since the cloud cover is a limitation on the use of optical data. With the launch of Sentinel-1 (1A in 2014 and 1B in 2016), radar data from the ESA Copernicus programme are now available globally, at a 12-day interval for 1 satellite, and a 6-day interval for 2 satellites, at a pixel size of 10 m and swath width of 250 km. The data, accessible from the Internet and free of charge, constitute the most suitable Earth Observation data for agriculture monitoring in Viet Nam. In the future, the Sentinel-1 series (1C, 1D, etc.) is already planned, to ensure data continuity well into the middle of the century and beyond. Currently, Sentinel-1 data are used for rice monitoring in Viet Nam in different research and development projects (*e.g.* the GeoRice and the VietSCO projects). The focus on using Sentinel-1 data for rice monitoring has stemmed from past research results demonstrating the adequation of the specific Synthetic Aperture Radar data at C-band frequency to rice monitoring [Le Toan *et al.*, 1997; Bouvet *et al.*, 2009, 2011; Lam Dao *et al.*, 2009, Hoang *et al.*, 2020; Phan *et al.*, 2021].

Using Sentinel-1 data, it is possible to generate maps at 10 m resolution showing the presence and the growth stage of rice every 12 days for Viet Nam. At the end of a rice crop season, maps of harvested rice area for that season are generated. Figure 4.3 shows the Winter-Spring 2019–2020 rice map of Viet

[Figure 4.3]
Distribution of rice crop using remote sensing



Left: Map of Winter Spring rice season in 2020 in Viet Nam. Right: details of rice distribution in Thai Binh, and An Giang. The maps are generated using time series from Sentinel-1 data, from the European Copernicus programme. Map pixel size at 10 m, indicating rice in red, water surface in blue, other land use land cover types in green.

Nam, with details illustrated for the provinces of Thai Binh, and An Giang. These maps provide temporal and spatial rice crop distribution that can complement the *in-situ* survey data for agriculture statistics. The other assets of remote sensing-derived maps are linked to the ability to quantify and localize annual changes in rice area and rice crop calendar, and changes from rice to other land use, for example aquaculture.

Figure 4.4 shows an example of the loss in the rice-harvested area in 2020 in the province of Ben Tre, as compared to 2019, for the dry season Winter-Spring crop. In most cases, rice was sown but the plant development stopped. In these coastal regions, the harvest losses are often caused by saline water intrusions and drought effects. To investigate these possible causes, a map of saline intrusions, and a graph of the drought index for the year 2020

[Figure 4.4]
Observation of the reduction in rice area in relation with drought and salinity intrusion

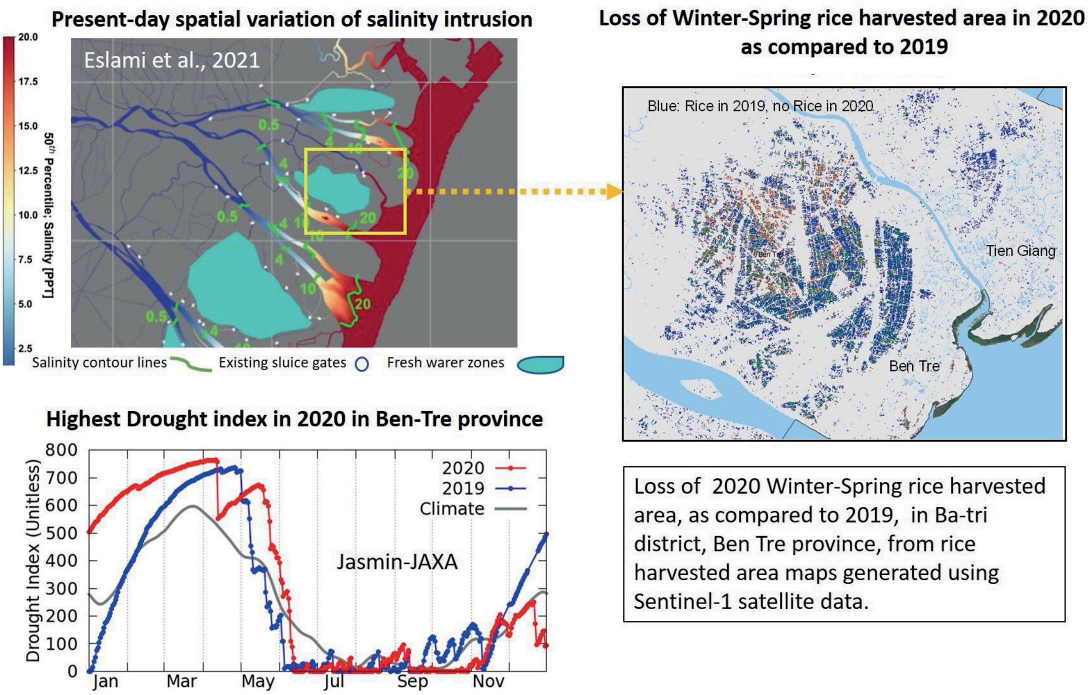


Figure 4.4 showing the reduction of Winter-Spring rice in the province of Ben Tre in 2020, as compared to 2019. Right panel: Change in rice harvested area from a comparison of the Winter-Spring rice map in 2019 and 2020. The blue color denotes rice-harvested area in 2019, and not harvested in 2020. Top left image: subset of the map indicating saline intrusions during a normal dry season [Eslami *et al.*, 2021], where salinity values in surface water (river, canals) are indicated, as well as the area of fresh water (in green color) protected from saline intrusion by sluice gates. Bottom left image: variation of drought index for Ben Tre, in 2020 (red), 2019 (blue) and for climatology (mean value over 2009-2014, in grey) from the Jasmin program developed by JAXA (the Japanese Space Agency).
https://suzaku.eorc.jaxa.jp/cgi-bin/gcomw/jasmine/jasmine_tsg.cgi

in the province of Ben Tre are also shown in Figure 4.6. In the saline intrusion map for a normal dry season [Eslami *et al.*, 2021], high salinity values are modelled in surface waters (river, canals) in Ben Tre, but rice could grow in the area of fresh water protected by sluice gates. In the graph of drought index for Ben Tre, the high drought index in January–April 2020 indicates that Ben Tre was hit by a more severe drought, as compared to 2019 and to mean values over 2009–2014. The loss of rice-harvested area in Ben Tre could therefore be attributed to the drought effect. Outside the fresh water area, it is possible that the harvest loss was also caused by saline intrusion.

2. Predicted agriculture productivity under climate stressors

2.1 Meta-analysis of the impacts of climate change on crop yield

Over the forthcoming decades, it is expected that the gaps to potential yield will be narrowed down for most crop types in Viet Nam as a result of technological progress. For rice, which is by far the main crop in Viet Nam, the yield appears to have reached a plateau (of about 6 ton/ha), at least for the last 5–10 years at the scale of the Red River Delta and the Mekong River Delta (see Section 1.2).

Climate changes will in this case become the major causes of annual yield fluctuations, and possibly of the long term decreasing trend. Therefore, the projected trends in climate stressors will play a critical role in determining XXI^{s} century agricultural production in Viet Nam. Given the complexity of the impacts on the range of crop types and the territorial diversity of the country, the magnitude of the impact that climate change will have on agricultural production cannot be determined unequivocally, and a large degree of uncertainty regarding these estimates is foreseen.

Research aimed at predicting the impact of climate change on agriculture production in Viet Nam is fairly recent (since 2010) and still rather limited. The main findings can be summarised as follows.

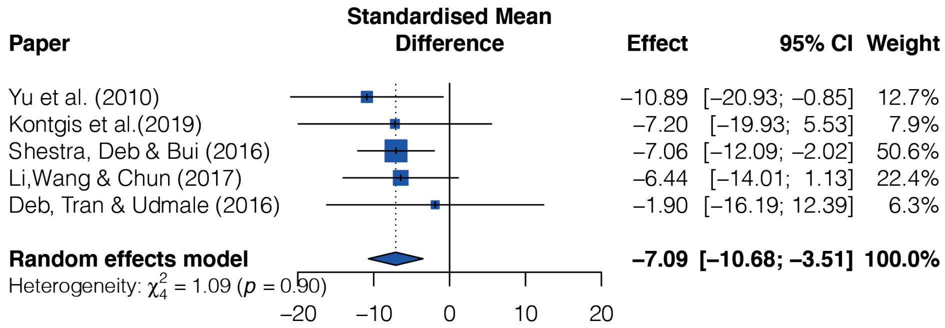
In general, most authors use crop models relating crop yield to climate indicators to simulate future yields under different climatic scenarios. The prediction results depend on the crop model used, the type of climate stressors (temperature, precipitation and others) considered, and the various climatic scenarios. Most studies estimate changes in crop yield by 2030 and 2050, for RCP4.5 and RCP8.5 climate scenarios, with respect to a baseline which is either the recent period's reported yields, or the potential yield.

Little research on Viet Nam has been undertaken to predict productivity of all crop types, and considering all climate stressors. For example, Gebretsadik *et al.* (2012) considered only water deficit as the main driver of productivity of tea, coffee, rubber, sugar cane, and other perennial crops and annual crops. Using a generic water deficit model to assess the impact of changing daily precipitation patterns on crop yields, the simulations for mid-century indicated a decrease in production for all of the crops, with yield reduction compared to potential yield ranging from -1.4% for annual crop, to -4% for perennial crops (tea, coffee, etc.).

However, most of the literature focuses on the impact of climate change on rice production, because of its importance in Viet Nam's agricultural sector. All authors agreed that climate change by 2050 will cause a significant reduction in rice yield, but the projections vary vastly depending on the rice crop season and the geographical area, indicating the importance of localized studies [Li *et al.*, 2007; Yu *et al.* 2010; Chun *et al.*, 2016]. Projections for the effects of temperature and precipitation at the province scale thus range from a small decrease or even positive impacts, to decreases greater than 30% [Deb *et al.* 2016, Shrestha *et al.*, 2016; Jiang *et al.*, 2019].

[Figure 4.5]

Meta analysis of past results on the impact of increasing temperature on rice yield



Meta analysis of the results reported in 5 selected published papers, on the impact of an increase of one degree of temperature on rice yield in percentage points. The weight given to each study result is calculated according to the 95% confident Intervals of the estimates.
Note: Effect = impact on rice yield (in %), SE = Standard Error (in %), SMD = Standard Mean Difference (in %).

The work by Bingxin Yu *et al.* (2010), goes beyond the impacts of changes in rainfall and temperature on crop yields. The authors present a yield function approach that models technological advances and policy interventions to improve rice productivity and mitigate the impact of climate change. Using a multilevel mixed-effects model, the results indicate that rice production is likely to be severely compromised by climate change. However, the study suggests that investment in rural infrastructure — such as irrigation and roads — and human capital can mitigate the negative impacts of climate change. Due to substantial regional variations in impacts and responses, localized policy packages were found to be key for effective mitigation.

Overall, the results obtained in the different studies show the likely adverse impact of climate change on the agricultural production of Viet Nam. The uncertainty and fluctuations in the estimates might be explained by different factors. Part of it can be explained by different crop models which do not take the same type of climate stressors into account, the different characteristics of the growing season, irrigation status, the geographical heterogeneity in the country, and, overall, the different future climate projections considered by the authors. Considering the uncertainties of the simulated results in the different research papers, a meta-analysis has been conducted to investigate the consistency of climate effects on crop yield across studies.

We performed a meta-analysis (random effects model) of the regression results to derive an average estimate of the change in rice yield, here as a function of temperature change. The input data are therefore the estimated slopes of the regressions and the associated standard deviations in individual studies. Figure 4.5 represents the outcome of a meta-analysis of five of the studies presented above, on the effect of changing temperature on the future rice yield. The effect reported is the impact of an increase of one degree of annual average temperature on rice yield in percentage points. By giving a weight to each of the studies depending on the precision of the estimates, the pooled effect is -7.09%. This means that by increasing the temperature by one degree, rice yields are estimated to decrease by 7.09%.

However an analysis which only considers the effect of mean annual temperature on future rice yield will need to be complemented by analysis of the temporal pattern of temperature (for example Peng *et al.* (2004) found that rice yield decline is caused by increase in nightime temperature). Also, the combined effects of temperature and precipitation need to be assessed.

Overall, despite the research's diversity of approaches, the review highlights the following:

- a decline of crop yield in Viet Nam, with yield reduction values of -4% for perennial crops and up to -10% for rice under RCP4.5 and -20% for RCP8.5, for the country as a whole; however, the predictions only considered the effects of long-term climate stressors (temperature and precipitation).
- substantial regional variation in impacts; the decrease could attain 30% for some provinces under study, for example. This indicates the necessity for localized studies, along with regional and national studies for mitigation measures,
- the need to consider not only the effect of projected temperature and water availability on crop yield, but also climate extreme events, which will result in the loss of crop production and, in the long term, in the reduction of crop habitat suitability.

2.2 Future projection of rice yield in the Mekong Delta

As stated in Section 1.2, crop yield (or crop productivity) depends not only on temperature and precipitation, but also on many other factors including soil characteristics, crop varieties, cultivation techniques, etc. In general, the trend in annual variation of crop productivity can be divided into two components: 1] trend productivity (due to changes in scientific and technical progress, such as varieties, fertilizers, farming techniques, etc.), which usually tends to increase over time and is usually approached using a linear function (cf. Figure 4.2); 2] weather productivity (due to changes in the environment, such as temperature, radiation, rainfall, saltwater intrusion, flooding, etc.), which depends on local conditions, and fluctuates from year to year.

In the Mekong River Delta, the mean rice yield for different crop seasons in 2020 is 6.01 tons/ha, but varies from 3.98–4.58 tons/ha (Tra Vinh, Camau provinces) to 6.14-6.56 tons/ha (Vinh Long, Dong Thap, An Giang, Kien Giang, Can-tho, Hau Giang) [GSO, 2020]. The yield also varies between crop seasons: the highest is Winter-Spring, owing to optimal solar radiation, in areas where irrigation water is sufficient, whereas the lowest is in Autumn-Winter, because of insufficient solar radiation and possible flooding effects. For example, the reported yields for 2020 in An Giang are 7.17 tons/ha, 5.83 tons/ha and 4.23 tons/ha; and in Tra Vinh, 3.54 tons/ha, 5.83 tons/ha and 3.78 tons/ha, respectively for the 3 rice seasons. The low yield in Winter-Spring rice in Tra Vinh could be linked to the lack of irrigation water and saline intrusion during the dry season.

For future rice yield prediction, only the weather impacts on productivity have been simulated through numerical models, taking projected local weather conditions into account. Up to now, many models have been used to simulate the growth and development of rice, and thus the final yield, such as:

WOFOST, SUCROS, ORYZA2000, SIMRIW, CERES-Rice, DSSAT, etc. Among these models, ORYZA 2000 has the advantages of being open source, easy to use, designed specifically for rice modelling, and continuously updated for new rice varieties [Bui T.Y. *et al.*, 2018].

This study used ORYZA2000, forced with projected climate data from RCP4.5 and RCP8.5 scenarios to project the 2030 and 2050 rice productivity in the Mekong Delta.

As mentioned in Chapter 1, two downscaling methods, *i.e.* the dynamical and the statistical ones, were used to build future climate change scenarios for Viet Nam, including the Mekong Delta. The first method used the 19 dynamical downscaling experiments, provided by the Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN). The second method is based on the Bias Correction Spatial Disaggregation (BCSD) experiments applied for CMIP5 GCMs. However, for the Mekong Delta, the two methods provided very close projection in temperature up to 2080 but rainfall results are remarkably different (cf. Chapter 7). In this study, we use the projections from the dynamical downscaling experiments, which are also used in the latest national report on climate change and sea level rise scenarios from IMHEN (2021).

The future rice yield of each province in the Mekong Delta is estimated for the period 2020–2050, based on climate projections according to the RCP4.5 and RCP8.5 scenarios. The impacts of climate change are quantified by a comparison between simulated annual rice yields of Mekong Delta provinces for Winter-Spring, Summer-Autumn and Autumn-Winter crops for the period from 2020 to 2050, and the average yield of the last fifteen years (2005–2020). The simulations have been based on hypotheses of the same cultural practices as present, and made use of an average crop calendar, rice varieties, and same crop management (irrigation, fertilization) for each province.

Using the method described in Bui T. Y. *et al.*, (2018), and extending the validation period from 2016 to 2020, the simulation results show that projected yield reduction varies between rice seasons and across provinces. For RCP4.5, future rice yields for the whole Mekong Delta could decrease by an average across the provinces of 4.10% in the Winter-Spring crop, 6.84% in the Summer-Autumn crop, and 6.71% in the Autumn-Winter crop. Yield reduction would be highest (-11%) in Dong Thap provinces for Winter-Spring crop; and Soc Trang (-13%) and An Giang (-13%) for the Summer-Autumn crop.

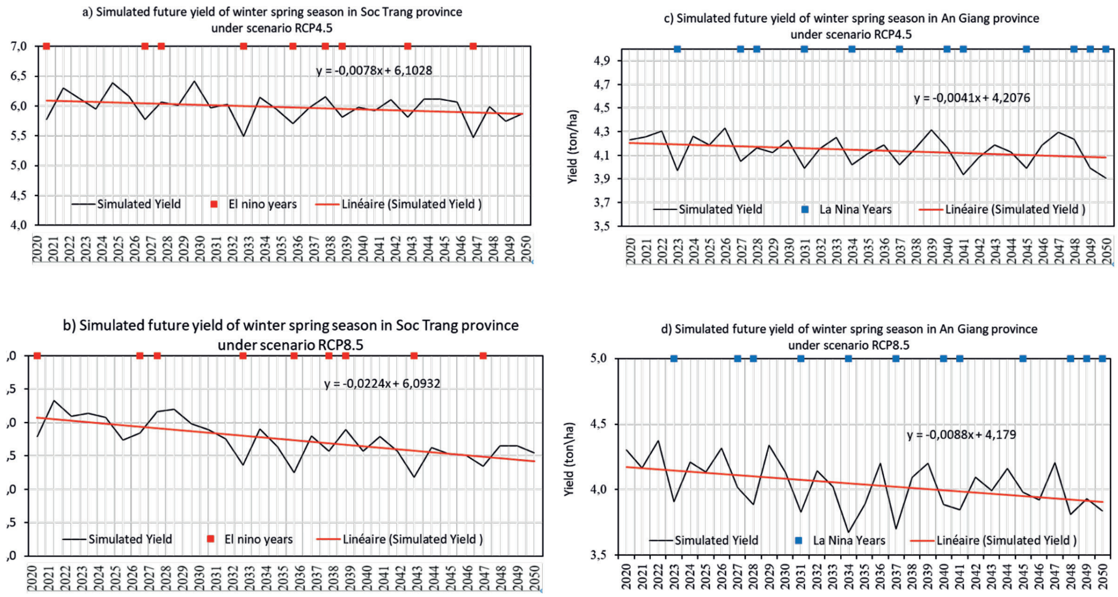
Under RCP8.5 scenario, the average reduction is estimated to be slightly higher, 6.38% in Winter-Spring crop, 9.40% in Summer-Autumn and 9.39% in Autumn-Winter.

It should be noted that in the simulations, the effects of flooding and saline intrusion are not considered.

Figure 4.6 illustrates the simulated rice yields of Winter-Spring in Soc Trang province and Autumn-Winter in An Giang province under RCP 4.5 [Figure 4.6 a,c] and RCP8.5 scenario [Figure 6 b,d]. It can be noted that the 30-year variations can be approached by a linear decreasing trend. By 2050, the average Winter-Spring rice yield is likely to decline to 5.5–6 tons/ha. Similarly, the average rice yield of Autumn-Winter is also likely to drop below 4 tons/ha. It should be noted that the simuled yield follows a decreasing trend from 2020

[Figure 4.6]

2020–2050 Model-based simulated rice yield for 2 selected provinces, under RCP4.5 and RCP8.5 scenarios



Rice yield simulated in the future, period 2020-2050, for winter-spring season, in Soc Trang province (left panels), in autumn-winter in An Giang province (right panels), for RCP4.5 scenario (top panels) and RCP8.5 (bottom panels). Red dots indicate El Niño year, with effects on winter-spring season in Soc Trang and Blue dots, La Niña year, with effects on autumn-winter season in An Giang.

to 2050, which could be approximated by linear trends. Annual yield fluctuates around the trend according to climate data input in the ORYZA 2000 model. During ENSO years, rice yields were generally below the trend line, while in El Niño years, factors such as temperature, evaporation, and sunshine hours are all higher, and rainfall lower than in a normal year during the period from April to May (Winter-Spring crop season). In La Niña years, rainfall for the Autumn-Winter crop is higher, while sunshine hours and temperature are lower than average.

In summary, the simulation results show a long term decreasing trend for rice yields in different provinces of the Mekong Delta, with accentuated inter-annual fluctuations during El Niño and La Niña years. However, the results could be updated by refining the input parameters used in the simulations. The most important improvements could be made by considering the geographical diversity of rice fields in each province, in terms of crop calendar, crop cycle duration, and irrigation practices, as observed by remote sensing satellites. This is the subject of current research work.

3. Projections of the reduction of crop area in the Mekong Delta

In many previously published papers, the focus has been mainly on the impacts of climate change on crop yield. However, for projection in crop production, the change in the number of crops per year and the reduction of the crop area need to be assessed. For this purpose, the methodology used in this study combines two research strands. The first, presented in section 2, is on the crop yield and the second, in this section, treats the projected changes in the area suitable for crop cultivation, which may lead to the reduction of crop-planted area.

Due to the complexity of studying all crop types in different eco-regions of Viet Nam, this study is focused on the rice crop in the Mekong Delta, driven by the importance of rice in Vietnamese economy [Kamil *et al.*, 2020], and also by the vulnerability of the Mekong Delta to climate change effects.

3.1 Projected reduction of rice grown area due to saline water intrusions

During the dry season, coastal areas of the Mekong River Delta face saline intrusions in surface waters. This natural process arises from the competition between the river and ocean forces within a given morphology, but is enhanced by anthropogenic activities in the Delta and sea level rise (see Chapters 7 and 9). Recent research has shown that the main driver of the increase in salt intrusion in the Mekong Delta observed over the past 20 years is river bed level changes, caused by sediment starvation from upstream dams and excessive sand mining [Eslami *et al.*, 2019].

Soil and water salinisation in the dry season is a problem for crop production in the coastal Mekong Delta [Tuong T.P. *et al.*, 2003; Carew-Reid, 2007]. During low river flow periods, between March and April, saline water intrudes up to 40–50 km inland from estuaries through main river systems. The Ministry of Agriculture and Rural Development [MARD, 2011] reported that, out of 650,000 ha of high-yielding rice grown in the lower delta, about 100,000 ha of rice annually is at high risk of dry-season salinity intrusion [Nhan *et al.*, 2012].

The two most important rice growing seasons in the Mekong Delta are the Winter-Spring and Summer-Autumn seasons that occur before and after the salinity surge, respectively. Salinity levels normally begin to rise by the end of December (early dry season), reach a peak in March or April (late dry season), and fall afterwards. The tail end of the Winter-Spring season is affected by rising salinity. Similarly, for the Summer-Autumn season, farmers wait for rainfall to flush salinity out of the soil and irrigation water canals before planting. Historically, severe saltwater intrusions occurred in 1998, 2010 and 2016, when salinity levels began to rise earlier and peaked with concentration levels higher than normal. Further, some coastal areas have been exposed to consistent saline intrusion, and farmers have transitioned from rice to other more salt-tolerant crops or aquaculture.

Salinity increases the osmotic pressure of the soil water solution and inhibits plant water uptake, impacting plant development and leading to reduced crop yield [Paik *et al.*, 2020]. Most of the rice varieties grown today are damaged when water salinity reaches 4‰ or more. For salinity levels above 2‰, rice yields were found to be reduced by 20–45% when salt stress occurred during the tillering stage, and by 10–40% if salt stress occurred during the heading stage [Paik *et al.*, 2020]. In addition to damaging rice crop in the field, the time required to leach salt out of the field increases with higher salinity values, causing delay and reductions in rice yield in the next cropping season. However, the salinity referred to in the literature is often soil or ground water salinity measured in-situ, whereas the salinity measured at stations is water salinity measured in rivers or canals [Hoang *et al.*, 2021]. Relating soil salinity to surface and ground water salinity in the case of salt water intrusion is difficult, and depends on different factors (soil type, presence of salinity barrier gates, timing and duration of the salt water intrusion, etc.).

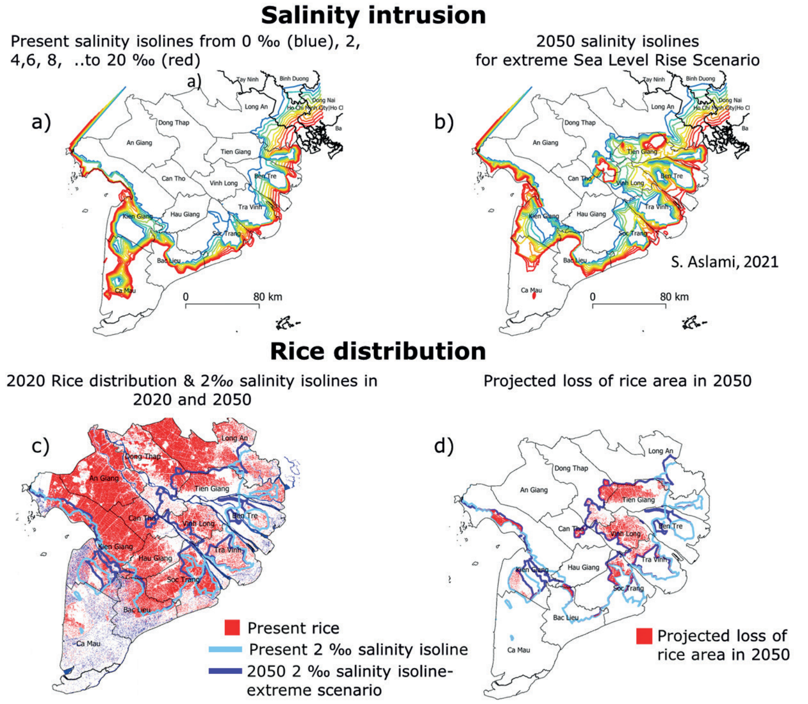
To investigate the effect of future salinity intrusion on Winter-Spring rice production, we have used simulations of surface water salinity under different scenarios (climate change and anthropogenic pressures) to assess which parts of the present rice-cropping area might become less suitable for rice cultivation.

Projections of surface water salinity have been taken from Eslami *et al.* 2021 (see modelling details in Chapter 9). Different simulations have been carried out to investigate the effect of climate change (sea level rise and river discharge anomalies) and of anthropogenic stressors (subsidence induced by groundwater extractions and riverbed level changes induces by sediment stravation) on future saline water intrusions. Results show that anthropogenic riverbed level incision could increase the extension of land impacted by saline water intrusions by 10–25% in 2050.

Figure 4.7 shows the contour lines of of saline water intrusions for the present [Figure 4.7a] and as projected in 2050 [Figure 4.7b], according to a worst case scenario: river discharge as projected in RCP8.5; subsidence rates as driven by an annual 4% increase in groundwater extraction; continuous increase in riverbed level incision, in line with current trends; extreme global sea level rise scenario (+60 cm). The contours are overlaid on the present Winter Spring rice map of the Mekong Delta, [Figure 4.7c] produced using Sentinel-1 data. Note that coastlines are assumed to be unchanged despite the high relative sea level rise, that would cause parts of the delta to fall below sea level.

In order to determine the concentration in water salinity that allows farmers to grow rice, our approach consists in calculating the percentage of the present Winter-Spring rice cropping area within different salinity isolines of 0, 2, 3, 4, 5, and 6‰ (at 50% of the time or P50). The result indicates that at present, 78% of rice in the Mekong Delta is grown where water salinity is below 0.5‰. 7.4% of the rice area is grown in areas where surface water salinity ranges between 0.5 to 2‰, and 3.7% in areas with salinity between 2 to 4‰. Only 0.56% of current rice is found in areas where salinity exceeds 4‰. The important finding is that only 4.26% of the present rice area is grown in areas where salinity exceeds 2‰ 50% of the time. Because the contour lines do not encompass all the rice in the Mekong Delta — rice in Ca Mau, for example, is in a salt-protected area — the total is less than 100%. Therefore, we assume that rice can be grown under 2‰ of water salinity, but with a reduction in productivity when salinity exceeds 0.5‰. The value of P50 = 2‰ is

[Figure 4.7]
Present and projected Salinity intrusion and Rice cultivation area



Impact of salinity intrusion on rice area. a) Contour lines of the present time surface water salinity from 0 ‰ the most inland to 2, 4, 6 ..20 ‰ (P50) ; b) Contour lines from the projection for 2050 under scenarios RCP8.5 (river discharge), with extreme scenarios for subsidence (B2), riverbed level changes (RB3) and sea level rise (+60 cm) (Cf. Chapter 9) ; c) Winter-Spring rice map overlaid with contour lines for 2 ‰ salinity (P50) for the present time (light blue) and for 2050 (dark blue); d) rice area (in red) which will be less suitable for rice cultivation in 2050.

chosen to roughly assess the future area suitable for rice cropping.

Figure 4.7c shows the map of the present Winter-Spring rice overlaid with the contour lines of 2‰, for the present time (light blue curve) and the projection for 2050 (dark blue). Figure 4.7d shows the portion of rice area which could be lost in 2050 in this extreme scenario (for water salinity > 2‰). In this case, 143 000 ha (or 10.5% of the 1.36 M ha of 2020's rice-harvested area) are found less suitable for rice cultivation in 2050. These are located mainly in the provinces of Tien Giang, Vinh Long, Tra Vinh and Soc Trang.

Mitigation of saline intrusion has been object of different measures [Nhan *et al.*, 2012]. In the MARD action plan to respond to climate change in the period of 2008-2020 [MARD & MOST, 2008], mitigation measures include: 1] development of large-scale salinity management structures (*i.e.* dykes, sluices and reservoirs), 2] development of small-scale irrigation infrastructures (*i.e.* canals, sluices, pumping stations), 3] development of adaptive farming technologies (*i.e.* crop varieties, farming techniques). For Nhan *et al.* (2012), in areas with salinity levels of up to 4‰, adaptive varieties and farming techniques could help farmers maintain their rice production and income. For salinity levels exceeding 4‰, the adaptation strategy could involve the conversion of rice culture to rice - shrimp rotational farming to improve farmers' incomes and livelihoods. However, since riverbed level incision driven by sediment starvation is currently the main driver of enhanced saline water intrusion and will remain the greatest threat at least for the first half of the century (see Chapter 9), the most efficient mitigation measure remains the control of sand mining.

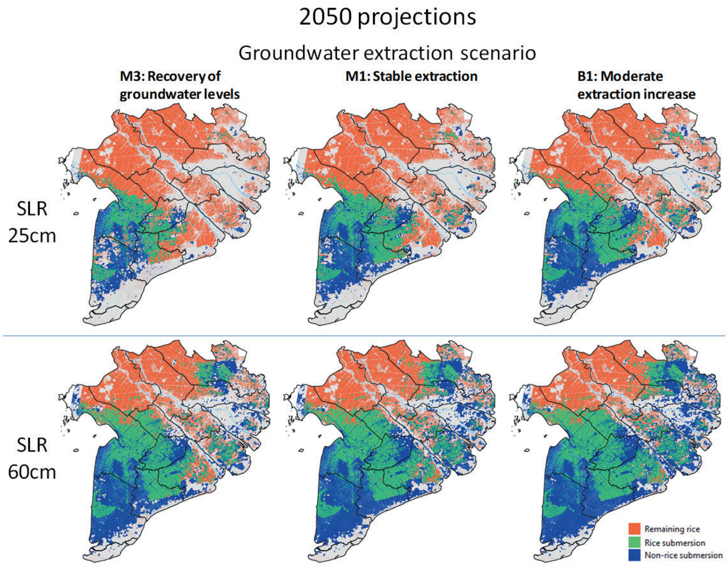
3.2 Projected reduction of rice-grown area due to potential inundation following relative sea level rise in the Mekong Delta

The combined effect of global sea level rise (SLR), land subsidence, and reduced sediment aggradation will cause the Mekong Delta to lose elevation relative to sea level [Minderhoud *et al.*, 2019]. Elevation loss increases the vulnerability to flooding and storm surges, and ultimately threatens the Delta with permanent inundation. Without adaptation, land that will be below sea level may be permanently inundated and no longer suitable for agriculture. In this study, we assess the extent of the present rice-grown area that is projected to fall below sea level, and is therefore at risk of inundation. For this purpose, we use projections of elevation changes based on scenarios of sea level rise and subsidence driven by groundwater extraction [Minderhoud *et al.*, 2019, 2020], as described in Chapter 9. As a first order assessment, we assume that there is no adaptation and that all land areas falling below mean sea level would be inundated. Inundation maps are simulated for 2050 under 3 groundwater extraction scenarios: scenario M3 is based on the recovery of groundwater levels (gradual reduction of extracted volume), in scenario M1, groundwater extraction rates are stabilized at present-day level, and in B1, there is a moderate increase of extraction (steady annual increase: 2% of the 2018 volume). Two global sea level rise scenarios are considered: RCP8.5 (+25 cm, MoNRE, 2016) and an extreme, low-probability, scenario (+60 cm), reflecting potential polar ice-sheet instability. Note that updated SLR median projections for Viet Nam by IMHEN (2021) range between +24 cm (RCP2.6) and +27 cm (RCP8.5) (see Chapter 1).

Figure 4.8 shows that with SLR of 25 cm, the percent of rice-grown area that would be unsuitable for rice cultivation due to permanent inundation by sea water is between 22% and 34%, depending on the subsidence rates induced by groundwater extractions. The impacts are on the low-lying provinces of Kien Giang, Hau Giang, Soc Trang, Bac Lieu, Can Tho and Ca Mau. For an extreme SLR scenario, the percentage of impacted rice area would range between 49% to 58%. The above-quoted provinces would lose most of their rice area, and in addition, Long An and Tra Vinh would be partly impacted.

In summary, for the Mekong Delta, projections of salinity intrusion and potential permanent inundation due to relative sea level rise strongly reduce the land suitable for rice cultivation. Nearly 10% of rice grown area during the dry season could be lost because of saline intrusion alone, mainly in the eastern provinces of Vinh Long, Tien Giang, Soc Trang,

[Figure 4.8]
Rice field extent lost by submersion (in thousand hectares and in%)



Rice area lost by submersion (in thousand hectares and in %)

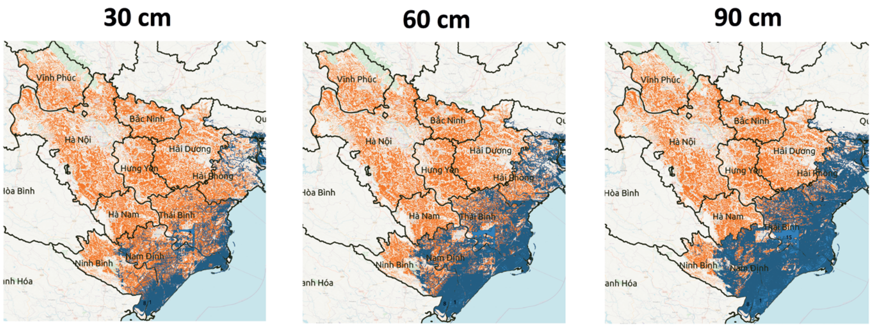
		Extraction scenario		
		M3	M1	B1
SLR scenario	25cm	3 871 (22%)	5 288 (30%)	5 995 (34%)
	60cm	8 666 (49%)	9 745 (55%)	10 254 (58%)

Maps of the 2016–2020 rice area that would be permanently inundated in 2050 under SLR of 25 cm (RCP8.5, top panels) and 60 cm (extreme, low probability) (bottom panels), along with 3 groundwater extraction scenarios, respectively in left, middle and right columns: in M3, recovery of groundwater levels (gradual reduction of extracted volume), M1: the same groundwater extraction (stabilizing extraction, no increase after 2020) , and B1: moderate increase of extraction at a steady annual increase: 2% of the 2018 volume. Red color represents non-submerged rice land, green color submerged rice land, and blue color submerged non-rice land.
The inserted table shows the extent (in thousand ha) and percentage of rice area lost by flooding, as compared to the rice extent in 2016–2020.

Tra Vinh. In the case of inundation of areas falling below sea level, the loss of rice grown area in the Delta is projected to be 22 to 34%, up to 58% in case of extreme global sea level rise, located in the provinces of Kien Giang, Hau Giang, Soc Trang , Bac Lieu, Can Tho and Ca Mau. In addition to this loss, the reduction of rice yield due to temperature, drought, and salinity (0.5 to 2‰) is forecast at the 35–45% of the non-submerged rice area.

Without adaptation, by 2050 and with SLR of 25 cm, up to 34% of the present rice-grown area could fall below sea level. Assuming adaptation measures are taken to avoid inundation, saline water intrusions could decrease the area suitable for rice cultivation by 10% anyway. For the remaining rice land, the rice yield is expected to decrease by about 10% compared to 2020.

[Figure 4.9]
2050 projections of rice cultivation area under permanent inundation caused by different projected SLR in the Red River delta



Loss of rice field extent by submersion (in thousand hectares and in %)

Province	Rice planted areas (thousand ha)	Rice areas lost (%) for 3 SLR scenarios		
		30 cm	60 cm	90 cm
Quang Ninh	21	49%	55%	58%
Thai Binh	82	11%	23%	66%
Hai Phong	38	3%	8%	53%
Nam Dinh	76	8%	29%	68%
Ninh Binh	42	1%	7%	21%

Maps of the 2016-2020 rice area generated by Sentinel-1 satellite data that would fall below sea level for sea level rise scenarios of 30 cm, 60 cm and 90 cm in the Red River Delta. In blue, the rice area that would be submerged, in red, the non-submerged rice land. The inserted table shows the loss of rice field extent by submersion in the impacted provinces (in thousand ha, and in percentage) for SLR of 30 cm, 60 cm and 90 cm for the 4 most important rice provinces in the Red River Delta.

In the Red River Delta

For the Red River Delta and the rice-grown area in the centre of Viet Nam, flood maps provided by MoNRE under scenarios of SLR of 30 cm, 60 cm and 90 cm have been used to assess the area and percentage of the present rice area that would be submerged. Figure 4.9 shows the maps of submerged rice area and the percentage of submerged rice area in the 5 impacted provinces. The impact on the two most important rice provinces, Thai Binh and Nam Dinh, is of the order of 10% for SLR of 30 cm, 23 to 29% for SLR of 60 cm, and 66 to 68% for 90 cm.

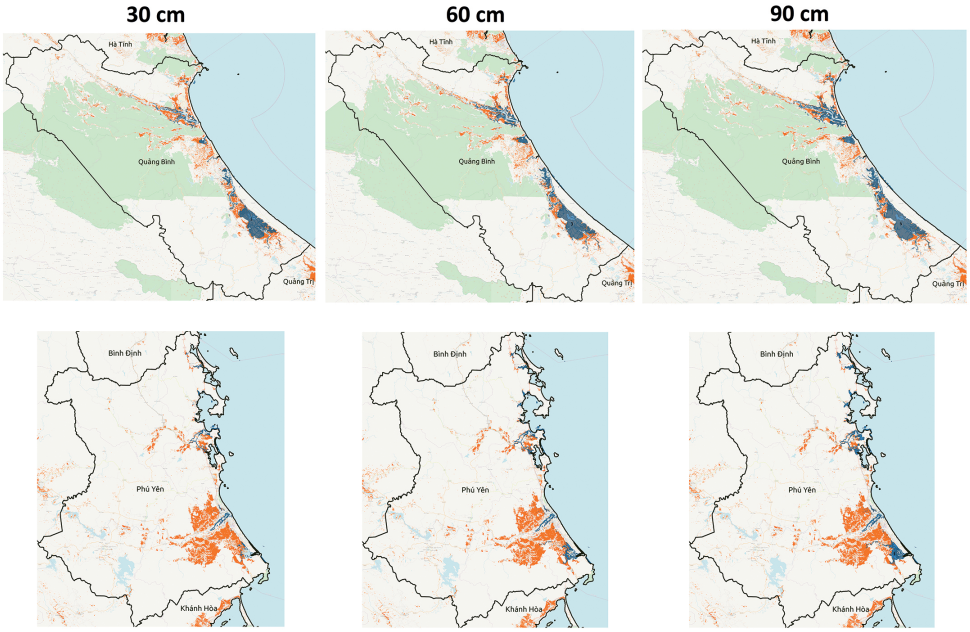
In summary, SLR of 30 cm will affect around 20,000 ha of rice area, and about 55,000 ha for 60 cm of SLR. The loss in rice area is much less important than in the Mekong Delta, however subsidence has not been taken into account. The effect of salinity intrusion also needs to be added.

In the Central provinces

In the central provinces of Viet Nam, the percentage of present rice cropping areas that would be impacted by sea level rise is smaller than in the Red River Delta. Figure 4.10 shows the maps of the two provinces in central pro-

[Figure 4.10]

2050 projections of rice cultivation area under permanent inundation caused by different projected SLR in Central coastal provinces



Loss of rice field extent by submersion (in thousand hectares and in %)

Province	Rice planted areas (thousand ha)	Rice areas lost (%) for 3 SLR scenarios		
		30 cm	60 cm	90 cm
Quang Binh	30	21%	33%	58%
Phu Yen	25.3	0%	0.7%	1.1%
Ninh Thuan	16	0%	0%	0.2%

Maps of the 2020 rice growing area generated by Sentinel-1 satellite data that would be submerged by flood water for sea level rice of 30 cm, 60 cm and 90 cm in Quang Binh (top panels) and Phu Yen (bottom panels) in the centre of Viet Nam. In blue, the rice area that would be submerged, and in red, the non-submerged rice land. The inserted table indicates the present rice growing area (in thousand hectares) , and the percentage of submerged rice land for SLR of 30 cm, 60 cm and 90 cm for the 3 impacted provinces in the Centre Coastal provinces.

vinces of Viet Nam which would be impacted by SLR: Quang Binh and Phu Yen. Because of the topography of the Central provinces, only Quang Binh will be impacted by loss of rice area, around 21% , 33% and 58% respectively for 30, 60 and 90 cm, as shown in the inserted table.

However, in order to insure consistency between assessments for the Red River Delta and the Central provinces with that for the Mekong Delta, projections need to be made with the same relative SLR scenarios, based on detailed elevation models; subsidence in the low land delta also needs to be accounted for.

4. The impacts of climate change on nutrition and food security

In the previous sections, the impacts of climate change on agricultural production, in particular for rice, have been assessed. However, food production is only one component where food security and nutrition related to the population are concerned.

According to the World Food Summit, held in Rome in 1996, "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" [FAO, 1996]. This definition shows the multidimensional nature of the food security concept. FAO identifies four main dimensions to understanding food security:

- The first dimension is availability, which means sufficient and quality food production available to households. This dimension refers to an adequate supply for a healthy diet, but does not take people's ability to get it into account.

- The second dimension, which is accessibility, is on the demand side. In addition to the first dimension, it takes households' access to sufficient food into account, in relation to the resources or opportunities they have.

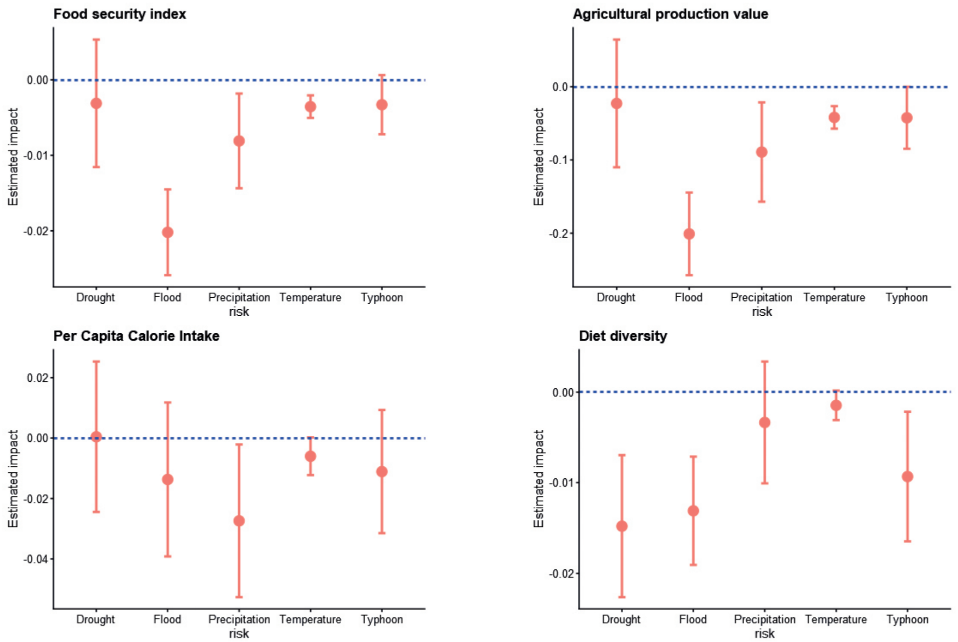
- The third dimension is diversity in the basket of foods consumed and the use of these goods. Indeed, a balanced diet is necessary for an adequate nutritional state.

- The last dimension reflects the stability of the three aforementioned dimensions. To ensure food security, households must have access to sufficient, healthy and diversified food at all times.

Most work on the impact of climate change on food security in Viet Nam has focused on the first dimension of food security, and dealt with main crop production (see section 3 of this chapter). The other dimensions have only recently become subjects of interest. Thus, in line with the recent work on poverty by Narloch and Ulf (2018), Yoro Diallo [Diallo, 2019, 2021] presents new insights on the impact of environmental risks on food security and nutrition in Viet Nam. We provide a detailed analysis of the associations between, on the one hand, different indicators on household food security and nutrition, and, on the other hand, different climate-related and environmental risks. The approach is based on data from the Viet Nam Household Living Standards Survey (VHLSS), conducted by Viet Nam's General Statistics Office (GSO). Estimations combine household data extracted from three VHLSS waves (2010–2012–2014), climate data (precipitation, temperature), and natural disaster data (drought, flood, and typhoon) from different global datasets [Diallo, 2021]. Only rural households are considered, as information on extreme weather event occurrence in VHLSS is only available for them.

Food security and nutrition indicators include the global food security index, total agricultural production, per capita household calorie intake, and diet diversity. Following Demeke *et al.* (2011), a food security index (FSI) is computed at the household level as the first component in a principal component analysis of different variables capturing the three first dimensions of food security. This component captures

[Figure 4.11]
Association of food security and nutrition indices with environmental risk



Food security index, agricultural production, calorie intake and diet diversity association with environmental risks.

41% of total observed data variance, and is mainly linked to the size of the farm (agricultural surface and production). Total agricultural production is measured by total value of crops including rice, vegetables, fruits, livestock, and aquaculture. This variable is taken as a proxy of food availability. Accessibility is proxied by a measurement of per capita calorie intake (PCCI) computed at household level using the same nutritional compositional table and PCCI computation technique as in Trinh *et al.* (2018). The diversity dimension of food security is proxied by a Simpson-type production diversity index [Vu, 2020].

Different environmental risks are taken into account. Of these, five are linked to climatic conditions: temperature and precipitation variability, occurrence of extreme weather events such as flood, drought, or typhoon. Each year, temperature (resp. precipitation) variability is computed as the deviation of average temperature (resp. precipitation) for this year from the five previous year average, in the commune where the household is located. Occurrence of extreme climatic events over the last two years is recorded at communal level in VHLSS.

Certain environmental risks have expected effects on some food security dimensions. For instance, Mendelsohn *et al.* (1994) found a nonlinear effect of temperature and precipitation on agricultural production in the USA. Furthermore, extreme weather events worsen rural household poverty [Arouri *et al.*, 2015], limiting their access to a diverse and high-quality diet.

Estimated associations, with 95% confidence intervals, are summarized in Figure 4.11.

Among the natural disaster variables, only the occurrence of flooding negatively affects food security as measured by FSI. A similar result is found regarding the impact of flooding on agricultural production. This consistency in the results for the two food security indices and agricultural production value is to be expected, as FSI mainly captures variability in the size of observed farms, which is measured using agricultural production. Nevertheless, mitigation tools for flood drainage and dyke protection against typhoons do not seem to be sufficiently developed.

The lack of impact of droughts on the FSI, agricultural production and Per Capita Calorie Intake can be explained by the irrigation strategy to adapt to climate change used by 40% of farmers. However, analysed VHLSS data from 2010 to 2014 do not cover the major drought events linked to El Niño in recent years, *i.e.* in 2016 and 2020.

Flood, precipitation and typhoon are found to impact household per capita calorie intake, but not drought and temperature. Households may substitute between food items when facing natural extreme events, and purchase food items that become cheaper compared to those whose prices increase due to the extreme event. This substitution effect seems to be corroborated by the negative significant impacts on diet diversity found for all the three considered extreme natural events, drought, flood and typhoon. In other words, Vietnamese farm households maintain constant calorie intakes when facing climatic shocks, at the cost of a significant decrease in their diet diversity.

Temperature shocks have a small but negative impact on all the dimensions of food security. Results exhibit the more significant negative impacts of precipitation shocks on all dimensions of food security, with a smaller effect on diet diversity.

In summary, analysis of the 2010–2012–2014 VHLSS survey data on four food security and nutrition indicators — *i.e.* global food security index, total agricultural production, per capita household calorie intake, and diet diversity — has shown that:

a] Climate and natural disasters affect food security through agricultural production,

b] Flood and precipitation affect food security index, agriculture production, and par capita calorie intake,

c] Natural disasters affect diet diversity.

The results on projected lost rice production due to flood, saline intrusions and climate change in section 3 would directly lead to a decrease in the Food Security Index, whereas natural disasters are expected to decrease the nutrition indicators in the future. However, the analysis needs to be completed with recent VHLSS survey data, before simulating future projections of food security and nutrition for different climate scenarios.

5. Adapting agriculture while reducing emissions

Over the past 30 years, strong agricultural growth has changed the socio-economic status of Viet Nam: improving food security, boosting agricultural exports, and creating livelihoods for people.

However, the previous sections have shown that the agricultural sector has already been impacted by climate change, and projections for the next few decades indicate that climate warming trends and athropogenic pressures are likely to continue to reduce agricultural production, unless there are effective measures for adaptation and mitigation (cf. Chapter 9). Further, these impacts are exacerbated by the pressures of increasing population and urbanisation, which threaten food security. (See also Yuen *et al.*, 2021). The most productive agricultural area of the country, the Mekong Delta, is forecast to be significantly impacted by relative sea level rise and saltwater intrusion, rendering the land less suitable for crop cultivation.

Viet Nam has been aware of the impacts of climate change for decades, and has been developing a robust policy framework to support adaptation strategies. In 2011 the government released the National Climate Change Strategy (2011–2020) [MARD & MOST, 2011], and in 2018, the National Adaptation Plan (NAP) (2020–2030), which stressed the importance of a comprehensive response to the impacts of climate change, specifically the threat to food security [MARD, 2018].

The NAP-Ag activities in Viet Nam aim to mainstream adaptation within the agricultural sector's planning processes. In order to maintain agricultural production in the context of increasing climate risks, many agricultural practices have been identified as having good adaptability to climate change.

At the same time, as part of the National Determined Contribution (NDC), Viet Nam aims to move towards low-carbon agriculture production. Climate change adaptation practices to be promoted for the agricultural sector should also contribute to mitigate Greenhouse Gas (GHG) emissions [Vietnam T.S., 2020].

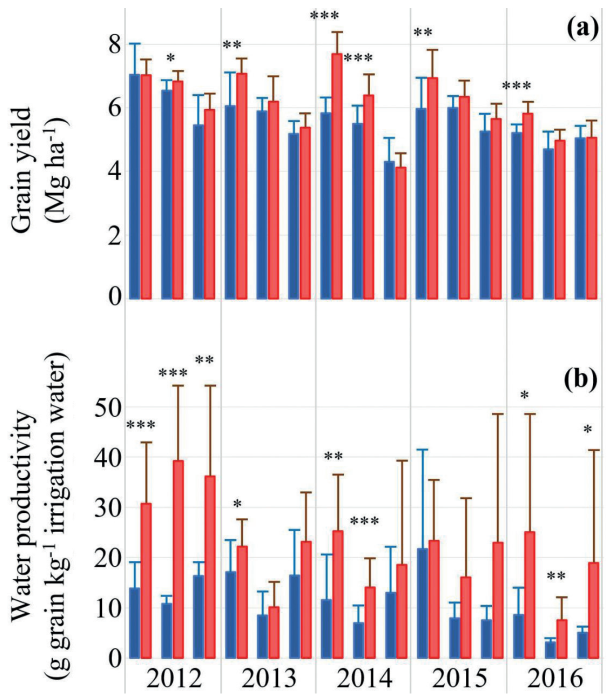
In fact, agriculture is the second-largest source of greenhouse gas emissions after the energy sector. The growth in agricultural production in recent years also creates significant impacts on the environment, as a result of the overuse of fertilizers, pesticides and irrigation water to increase productivity.

Among agricultural crops, rice cultivation is the most important source of GHG emissions. Viet Nam harvests around 7 million hectares of rice annually (7.470 million hectares over 4.129 million hectares of paddy land, according to GSO 2021), and methane emissions from rice production are responsible for 50% of emissions from agriculture, which in turn contributes 33% of the country's total greenhouse gas emissions. Therefore, improving rice production practices is key to reducing agricultural emissions.

Until now, intensive rice farming, which relied heavily on irrigation, has provided huge productivity gains under conditions of intensive resource use. Hydraulic controls, regulating floods and preventing saline intrusion have boosted production in the Mekong Delta and elsewhere. This has partly been through land reclamation, but mostly by enabling double or

[Figure 4.12]

Reduction of water use by AWD irrigation practices (blue) compared to Continuous Flooding, without significant impact on grain yield



Effect of Alternating Wetting and Drying versus Continuous flooding. Rice grain yield (Mg per ha) (a), and water productivity (g grain per kg of irrigation water) (b). Rice grain yields are shown for 14% moisture content equivalent. Values of continuously flooded field-water treatment (CF) and of alternate wetting and drying field-water treatment (AWD) are shown respectively as blue and red bars, which are arranged in chronological order from left to right, started from the winter–spring crop of the experimental year 2012. Error bars show standard deviations (n = 9). Significant differences between CF and AWD analysed according to Student t test are shown as *, **, and ***, respectively denoting significance at 10%, 5%, and 1%.

triple cropping in a single year. However, rice production is increasingly constrained by water scarcity and climatic events. High dependency on energy and technologies have also increased the fragility of the rice farming system.

Advanced farming practices have been recommended, such as integrated crop management (ICM), and 3 Reduction 3 Gains (3G3T) cultivation techniques (promoting the reduction of the three inputs seeds, fertilisers and insecticide to bring three benefits: increased income, lower exposure and risk due to pesticides, and an improved environment with less pollution from farm chemicals), 1 Must 5 Decreases (1P 5G), integrated disease management (EPM), improved rice cultivation system through the System Rice Intensification (SRI), which recommends sowing sparsely, irrigating fields that are alternately flooded and non-flooded (Alternate Wetting and Drying, AWD), and reducing the use of chemical fertilisers and plant protection products. Emissions from rice paddies can also be reduced by rotating the use of land, by introducing alternative activites like shrimp or fish farming. For example, instead of having three rice crops a year, a farmer could produce two rice crops and one shrimp harvest in the same paddy.

Creating a favorable environment for agricultural production to adapt to climate change and reduce emissions is one of Viet Nam's top priorities. However, the conflict between the long-term and the short-term interests of agricultural growth is a factor that limits the application of these good practices on a large scale in Viet Nam.

In this study, the focus is on the AWD practice, which could be applied as a measure of adaptation to the future scarcity of water, and a major measure in reducing GHG emissions.

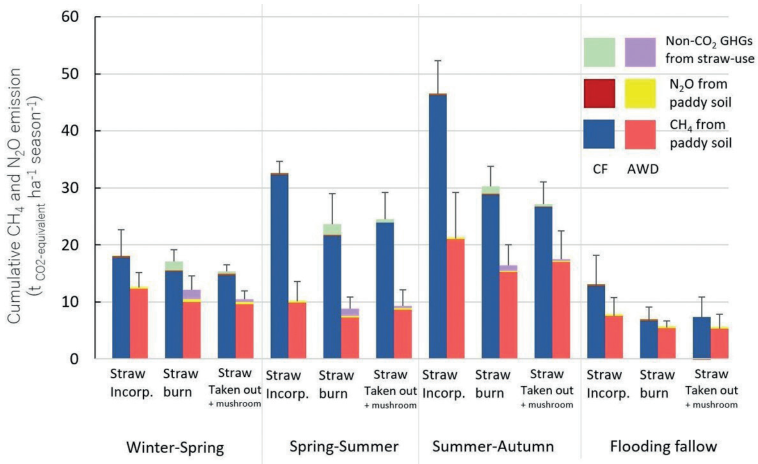
Rice production requires large amounts of water (3,000-5,000 L kg^{-1} rice, IRRI 2001), and has become a major source of the potent greenhouse gas methane (CH_4); about 11% of anthropogenic CH_4 emissions come from rice paddy submerged soils [IPCC, 2013], and among the major cereals, rice has the highest global warming potential due to the high CH_4 emissions [Linquist *et al.*, 2012]. Therefore, water-saving irrigation practices, which can potentially mitigate CH_4 emissions by oxidizing the soil environment (*e.g.* AWD), are should be disseminated in Viet Nam to ensure sustainable water demand, while lowering greenhouse gas emissions.

For drought and saline intrusion, water saving irrigation techniques are required as a counter measure. However, according to traditional knowledge, water saving irrigation could be detrimental to rice yield. The question was studied during the last decade by experiments conducted to compare rice productivity and water productivity between Continuous Flooding (CF) and Alternate Wetting Drying (AWD). It was found in triple-cropping rice paddies in the Mekong Delta that the yield does not decrease, but rather increases slightly under AWD [Arai *et al.*,2021; Uno *et al.*, 2021], whereas irrigation water productivity (grain weight per litre of water used) is significantly increased [Figure 4.12].

At the same time, the annually cumulative GHG CH_4 emission is significantly reduced. Figure 4.13 shows the results obtained from the 5-year experiment in 2012-2016 [Arai *et al.*, 2018], for which CH_4 and N_2O were measured. Different ways of managing straw after the harvest have also been studied (straw incorporated in the soil, straw burned and straw removed from the fields). The results show that a] CH_4 emissions is highly reduced by AWD for Spring-Summer rice and Summer-Autumn rice, for which the emissions are highest; the reduction is more moderate for the Winter-Spring dry season, and the fallow period, b] straw incorporated has the highest emission following the decomposition of the organic matter, c] annual nitrous oxide emissions make up only 0.2–7.1% of total greenhouse gas emissions (*i.e.* CH_4 + N_2O, CO_2 equivalent), and were negligible compared with CH_4 in terms of the global warming potential of the rice cropping system. These results indicate that intermittent irrigation is the most efficient way to reduce the total greenhouse gas emissions of rice production. In addition, straw incorporated in the soil must be avoided.

Regarding water saving under AWD, it is recommended to irrigate the fields when the water level drops to -15 cm beneath the soil level. However, it is difficult to locate the

[Figure 4.13]
Reduction of GHG emissions by Alternate Wetting and Drying (AWD) irrigation as compared to Continuous Flooding (CF) of rice fields



Cumulative methane from rice fields for continuously flooded fields (blue bar) and AWD fields (red bar). Nitrous oxide (N_2O: brown/red bars) and non-CO_2 greenhouse gases (GHGs: including carbon mono oxide, CH_4, N_2O and non-methane volatile organic carbon, as described in Arai *et al.*, 2016). The emissions are for three ways of straw management during each cropping season (winter-spring, spring-summer and summer-autumn) and flooding fallow season during 5 years from 2012 to 2016. Error bars show standard deviations (n = 3 samples ×5 years).

rice fields where AWD is effectively applied in the Mekong Delta. By assimilating radar data from the ALOS PALSAR satellite into the model, we found that about 22% of total rice paddy areas in the Delta were continuously flooded or irrigated before the water level drops to -5 cm [Arai *et al.*, 2021]. These results indicate that the Mekong Delta, like all the rice-growing regions in Viet Nam, still has huge potential to reduce its methane emissions and adapt to the predicted scarcity of water.

6. Summary

According to the 6th IPCC Assessment Report, global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the XXIst century, unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades. Many changes in the climate system have become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of extreme heat, heatwaves, heavy precipitation, agricultural and ecological droughts in some regions, and the proportion of intense tropical cyclones [IPCC AR6, 2021].

With sea level rise affecting the Deltas and coastal regions, and with changes in precipitation pattern leading to flood and drought, Viet Nam is heavily exposed to the risks of weather variability and climate change. Long-term climate change and weather shocks have strong impacts on crop productivity and future crop geographic distribution. Temperature and precipitation patterns and extremes, saline intrusion, floods and droughts are predicted to cause major declines in crop productivity and crop area.

The impact of climate scenarios on crop productivity has been examined using a range of agronomic models, which take temperature, rainfall patterns, water availability, and other factors into account. Predicted changes in yields vary widely across crops, agro-ecological zones and climate scenarios, but most findings concur on the decline of crop yield under climate scenarios RCP4.5 and RCP8.5.

In terms of crop geographical distribution, for the climate change scenarios in 2030 and 2050, climate factors (temperature, precipitation, solar radiation, etc.), weather extremes, flood patterns, and saline intrusion will change in all agro-ecological zones, but the changes vary from North to South, and from coastal to inland areas, affecting the habitat suitability of rice and other major crops. This could have drastic effects on crop distribution in the future. It should be noted that the main threats for rice cultivation in the Deltas are relative sea level rise and increased saline intrusions, and that both phenomena arise mainly from anthropogenic pressures (groundwater pumping and sand mining).

Most of the emerging solutions in the agricultural sector for the next decade should focus on improving the sector's resilience in the face of weather, biological, environmental, social and commercial risks. Before adaptation, attenuation measures should be undertaken. For rice cultivation — the main component of the agricultural sector in Viet Nam — human pressures on the environment should be reduced. These include exploitation of groundwater and sand mining in the Deltas, and the practice of continuous flooding in all rice-growing regions in Viet Nam. On the other hand, the agricultural outcome should be quantified not only by the amount of harvest crops, but also by the market value of the crops and the cost of damaging the environment, while for vulnerable populations, food security and nutrition should be taken into consideration.

Approaches to risk management in agriculture — which will also constitute climate change adaptation measures — should therefore cut across infrastructure, technology, natural resource planning, management practices, and financial instruments.

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