IOP Conference Series:
Earth and
Environmental Science

PAPER • **OPEN ACCESS**

Changing agricultural practices as a result of variable water resource availability in a hilly area of An Giang province, Vietnam

To cite this article: D N Huynh *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1306** 012014

Changing agricultural practices as a result of variable water resource availability in a hilly area of An Giang province, Vietnam

D N Huynh[1,2], V H T Pham[1,2,4] and N V Duong[3]

[1] Faculty of Agriculture and Natural Resources, An Giang University, 18 Ung Van Khiem Street, Long Xuyen City, An Giang Province, Vietnam
[2] Viet Nam National University, Ho Chi Minh City, Viet Nam
[3] Agriculture and Rural Development Faculty Kien Giang University, 320A, 61 National high way, Minh Luong Town, Chau Thanh District, Kien Giang Province, Vietnam

Corresponding author email: phtvan@agu.edu.vn

Abstract. Located in the Southwest of the Mekong Delta in Vietnam, An Giang province is an important center of agricultural production, especially rice cultivation. Climate change impacts are one of several man-made factors affecting water resource availability for agriculture in the province. It is recognized that new solutions are crucial to adapt to the present and future conditions of a scarcer water supply. This paper explores climate factors affecting water resource availability in agriculture and some recent adaptations being adopted by farmers in one district of An Giang province. Hydro-meteorological data was collected together with in-depth interviews as a tool to point to proximate changes in water status and availability and to evaluate local inhabitants' awareness of climate risks and adaptive strategies. The results noted that climate factors (temperature, humidity, annual rainfall) have altered over time, causing decreased availability of water supplies for agriculture. Recognizing this situation, both structural adaptation and non-structural solutions may occur simultaneously to maintain agricultural production efficiency. The types of crops, tolerant varieties, and irrigation projects suitable for various geographical areas were considered for more adaptive agriculture production locally. To address some of the problems that farmers face, water-saving technologies are an essential part of a range of potential solutions to maintain agricultural production and protect the environment in the future.

Keywords: Agricultural, production, hydro-meteorological

1. Introduction

Vietnam is recognized as one of the most vulnerable countries in the world to the impacts of climate change [1, 2, 3]. The effects of climate change include rising temperatures, changes in the intensity of rainfall, more severe and frequent typhoons, increased flooding and erosion, raised sea levels and saline intrusion, and probably intensifd droughts that can lead to the degradation of the environment, the destruction of human communities and infrastructure and inevitably, reduced agricultural production capacity, with impacts most acute in developing countries [4, 3]. Tropical delta regions, such as the Mekong and Red River deltas, are at the frontline of anthropomorphic climate change, with impacts

increasingly being felt over recent years, often exacerbated by other human-induced environmental impacts. Such combined and synergistic impacts affect the Vietnamese poverty-reducing strategies and influence the millennium goals of sustainable development [1]. As a result, vulnerable communities may face food shortages and diminished livelihoods in the short to medium term. In the longer term, recent projections state that most of the Mekong Delta is likely to be inundated by rising sea levels and increased coastal erosion by the end of the 21st century, implying vast adaptation measures will be necessary if human communities and other terrestrial fauna and flora populations are to survive [5, 6].

The Mekong Delta, located in the far south of Vietnam, is the third-largest delta worldwide and covers an area of approximately 39,000 km^2, and has a population of over 16 million persons [7]. The Mekong Delta water resources are recognized to be faced with several growing environmental pressures besides climate change factors, most especially upstream dams altering the river's hydro-sedimentary regime, construction of hydraulic control infrastructure, including drainage canals, erosion protection, and irrigation schemes, rising water pollution from industrial and domestic sources, serious levels of groundwater and surface water abstraction and sand mining activities exacerbating erosion rates [8]. The Mekong Delta climate is tropical with two distinct seasons, incorporating a dry and monsoonal wet season [9, 10]. The annual average temperature is about 27^{0}C; the highest temperature of the year usually occurs in April, and the lowest is in December [11]. Annual precipitation is approximately 1,500 – 1,800mm, with normally a peak in rainfall during August and September when cyclones and tropical storms can hit the region.

Giang province is located in the upper part of the delta, and it has a reputation as an intensive production region of rice, freshwater aquaculture, vegetables, and fruit. In 2018, rice production in An Giang reached 3,927 million tons, and aquaculture production was approximately 486,800 tons [12]. Recently, there is evidence to suggest that agriculture is being affected by climate change impacts, alongside a range of other challenges, and some of these impacts tend to be more severe in hilly areas due, for example, to shortages of water in the dry season, as rainfall has become less predictable. Various research has been conducted in the past to study water and how it affects agricultural activities [13, 14, 15]. However, there is relatively little understanding of how water resources have been affected by climate change and other pressures and responses to ongoing changes by local institutions and farmers. Another major factor affecting water availability, as well as being a contributory cause of the delta's ongoing "sinking and shrinking," is "excessive" groundwater withdrawal, claims [8]. The study was conducted in Tinh Bien, a district of An Giang province with a series of prominent hills rising out of the deltaic floodplain, to explore some of the climate factors affecting water resources and local adaptation strategies that are trying to mitigate or overcome temporary or seasonal shortages in water supply for agriculture. The paper aims to evaluate how water resources have been affected by climate factors and to what extent the local institutions and farmers have been required to change agricultural practices in response to the changing situation. Towards the end, some brief suggestions are made about potential ways the agricultural sector may better adapt to climate change impacts in the future.

2. Method

2.1 Research site

A Giang is a border province (figure 1a) adjacent to the Cambodian provinces of Kandal and Takeo lying to the north. The province has some quite different natural characteristics compared to the rest of the provinces in the Mekong Delta, with the terrain comprised primarily of flat floodplains of the main distributaries of the Mekong and a few prominent hills [16]. The hills, composed of volcanic rock, rise out of the wetlands landscape and have been settled by mostly Khmer ethnicity villagers for many centuries. A Giang is currently facing several challenges in the context of climate change, with generally rising temperatures, floods, droughts, and thunderstorms [17].

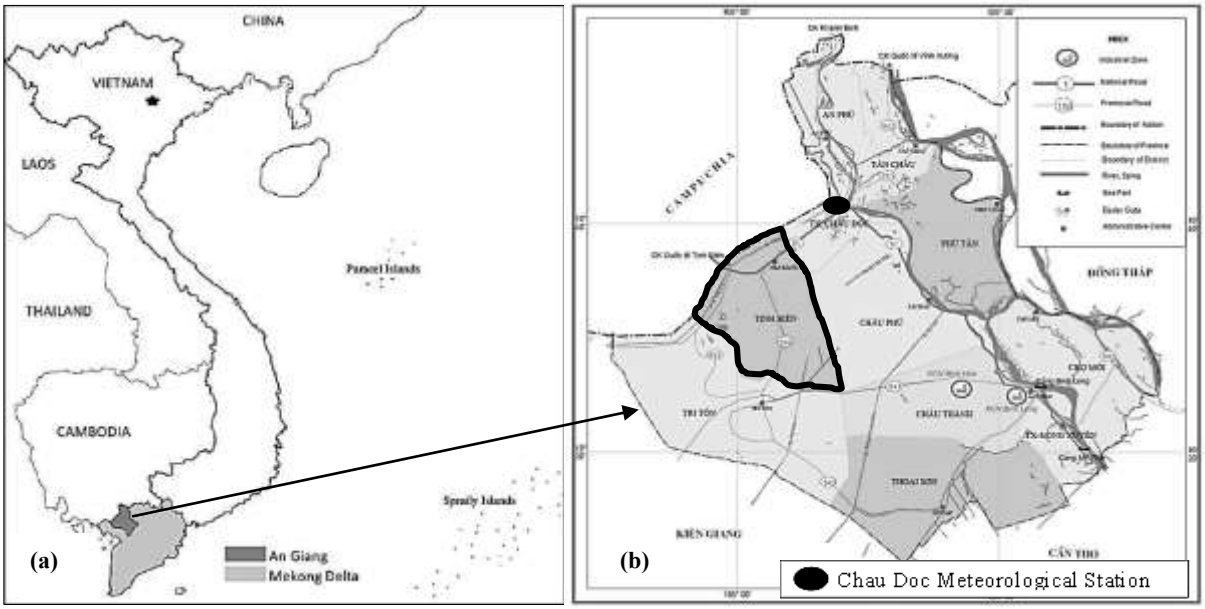

Figure 1. The Vietnamese Mekong Delta and location of An Giang province (a); the research site in Tinh Bien District and location of the Chau Doc meteorological station (b).
Source: [18, 19]

Tinh Bien district was selected as the study site because it has been affected by climate change impacts, as have all provinces of the delta to a greater or lesser degree. The location of Tinh Bien district in An Giang Province is shown in Figure 1, b. Basic information about the study area is shown in Table 1.

Table 1. Some basic data of Tinh Bien district in An Giang Province.

Facts	Description
Land area	35,459.1 ha, equivalent to about 10.03% of the provincial area.
Population and Ethnicity	108,485 people (2019). Kinh (majority) and Khmer (minority) are the main ethnic groups of people.
Density	306 people/km^2 (2019).
Administrative units	Three towns and 11 communes.
Tide regime	The Canal system is affected by the semidiurnal tide from Hau River (*two high and two low tides of approximately equal size every lunar day).*
Topography	Topography can be classified into three main areas titled as the alluvial field, the high field, and the hilly area.
Main crops	Rice, maize, sweet potato, cassava, legumes, short-term industrial crops, fruit trees, and medicinal plants.
Agricultural sector	The gross output (GO) of the agricultural sector in 2019 was 37,750 billion Viet Nam Dong accounting for about 97% of the total GO of the district.

Source: [20, 21]

2.2 Data Collection and Analysis

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity [22]. Locally, however, climate change impacts may be more difficult to perceive by

people and, to a certain extent, to measure. The specific context is essential to appreciate a specific climate change event [23]. In this case, the concept of climate risk is applied to describe the result of climate change and its effect. Water, as an indispensable agricultural input, is considered a climate risk variable. In this study, adaptation is defined as adjustments in ecological and social systems in response to actual climatic stimuli and their impacts [23, [24, 25]. Adopted the science of adaptation concept for adaptive strategies [26], the theoretical framework has been created to guide the research as shown in Figure 2, displaying the relationships between climate risk effect and action to respond in the case study area.

.

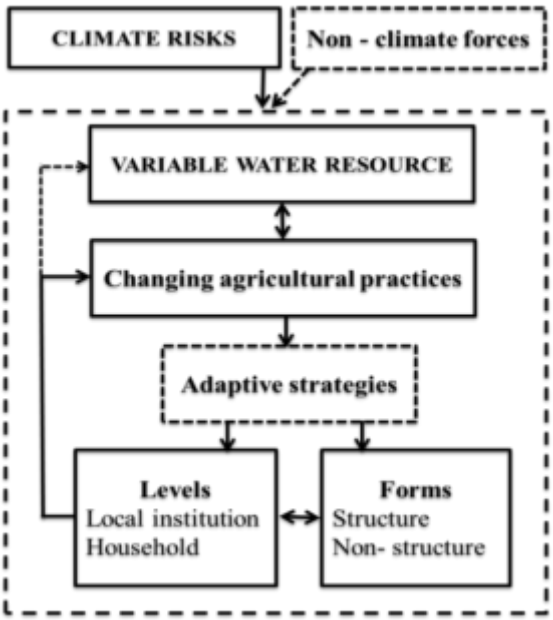

Figure 2. The framework to study changing agricultural practices to variable water resources in An Giang province
Source: adapted from [26]

The framework indicates three main research foci, as follows:

- Understanding the climate factors that affect water resource availability.
- Exploring changing agriculture practices as adaptive solutions to variable water availability
- Forms of adaptation and the relationship for better use of water for agriculture at different levels.

In the study, the main focus was on the climatic factors affecting the change of water resources, while non-climate forces were not considered in any detail.

2.2.1 Data collection: A mixed-method approach using both qualitative and quantitative data sources was used. The main methods were a desk study, in-depth interviews, and direct observation.

- A desk study was conducted as a first step to gain access to the archives held at government institutions at different levels and reports relevant to climate factors affecting water resources, changing agricultural practices in the target area, and any future development strategies.
- In-depth interview: Key informant interview was used to question local authorities in the Agricultural and Rural Development Department, Environment and Natural Resources Department, Cultivation and Plant Protection sub-department, Commune officers (KIP- Key Informant Panels), and farmers to get a general understanding of water resource, water management, current agricultural practices and solutions for future adaptation. A total of fourteen meetings were conducted. Fourteen people (six officers and eight farmers) were interviewed individually due to the effects of the Covid 19 Pandemic.
- Field survey, the interdisciplinary team, went to the study area to observe the irrigation system, water management process, and crop structure at different times of growing time (land preparation, pumping water, and harvesting time). Three field trips were conducted in November 2020, March 2021, and June 2021. The trip lasted from 2 to 3 days; the research team went to the area to contact local officials for field reference.
- To gather four types of climate data at the Chau Doc hydro-meteorological station in 25 years (1996 to 2020), namely rainfall, temperature, humidity, and highest flood level. Since Chau Doc is a regional station in An Giang province belonging to the national network of stations in Vietnam, there is no meteorological station in Tinh Bien, but Chau Doc (25 km away) is used as a proxy site.

Data analysis: Climate data was collected and calculated to get the mean for the year (temperature, humidity), the total annual rainfall, and the highest flood level of the year. The extensive and raw qualitative data are condensed into a brief and categorized into different categories. They are selected to correspond to the research objectives. The findings were documented and discussed according to the outcomes of the research.

3. Findings and discussion

3.1 Variation of climate factors and Relationship to Agriculture

Climate data displays that average annual rainfall, temperature, humidity, and the highest flood water level have changed in An Giang over the past 25 years.

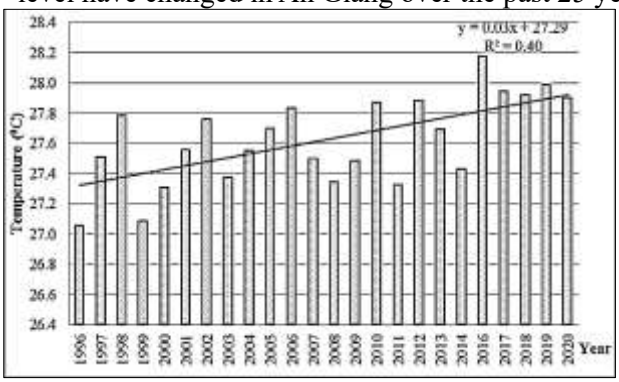

Figure 3. Figure 3. The increasing trend in mean annual temperature from 1996-2020 at Chau Doc hydro-met station.

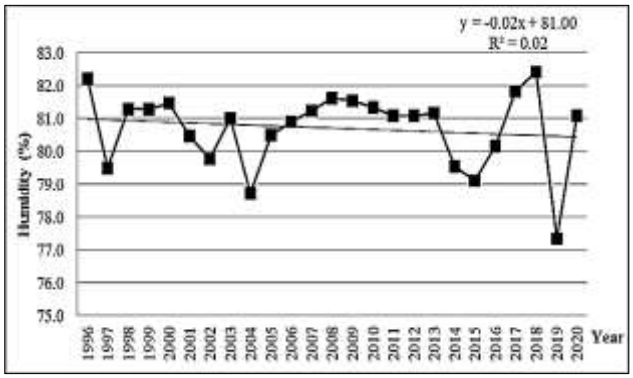

Figure 4. Trends in mean annual humidity from 1996-2020 at Chau Doc hydro-met station.

Figure 3 shows that the annual average temperature has tended to increase gradually over the last 25 years. The data coincides with a previous study showing that the average temperature in the Mekong Delta has fluctuated over the years, but the general trend has tended to be upwards [1]. By contrast, the annual average humidity in An Giang has tended to decrease slightly over the same period (figure 4). The average humidity in An Giang varies from about 83 - 84% in the rainy season and is slightly lower (77 - 80%) in the dry season [27].

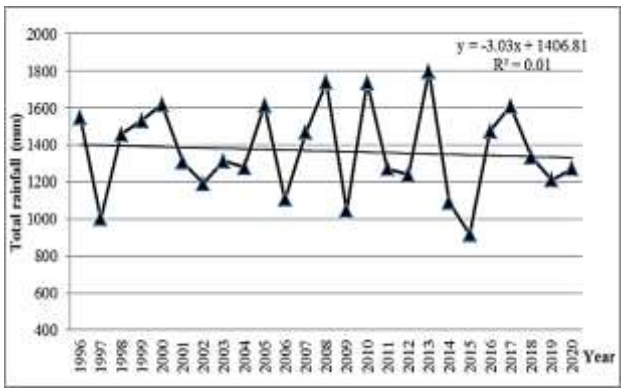

Figure 5. The trend in annual average rainfall at Chau Doc hydro-met station from 1996-2020.

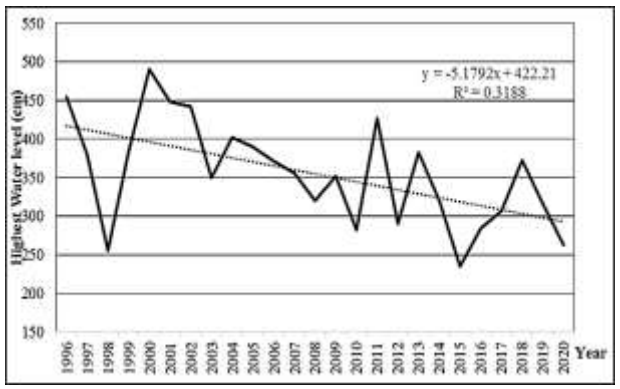

Figure 6. The sharp decline of the highest flood water level on Hau River from 1996 to 2020 in An Giang province.

Figure 5 shows that the average annual rainfall in An Giang has tended to decrease over the 25 years. The annual average rainfall in An Giang is about 1400-1500 mm [11]. It is less than the average rainfall of Vietnam (which averages around 1,800 mm per year). However, the annual distribution is highly uneven because the country lies in a tropical monsoonal region. Typically, 80–85% of the total rainfall occurs in the wet season from May to November [28], which may affect the water resource available for agriculture.

The hydrological characteristics of An Giang province strongly depend on the water volume of the Mekong River. In the entire Mekong Delta, the annual flood plays a vital role in underpinning the productivity of the entire system (*the flood season occurs in the rainy season from May to November*), under normal conditions depositing a large amount of alluvium on the floodplain, maintaining water tables and providing a variety of ecosystem services, including enabling a high output of aquatic resources that have traditionally supported local livelihoods [29]. The height of floodwater has an important influence on the alluvial deposition in the field [15]. The results show that the flood water level in the past 25 years has tended to decrease sharply (figure 6). As Park et al. (2020) maintain, the main factor that has reduced the frequency of flooding has been river-bed mining of sand and extensive dyke construction, effectively cutting off the floodplain from the main river channels. Many large reservoirs and dams store vast quantities of water upstream in China, Cambodia, Laos, Thailand, and Vietnam, massively altering the annual hydrograph and reducing downstream water availability, with one outcome being that large floods now rarely occur, so floodwater and associated sediment and nutrients hardly ever reach farmer's fields [13, 30].

Being considered a climate risk, water resource has influenced many sectors, especially agricultural production. Research on agriculture in the Delta of Vietnam has shown that farmers face a wide range of climate-related and eco-hydrological factors which threaten rice production [31]. In Tinh Bien district, agricultural land accounts for 84.49% of the total area, and 71.69% of the population lives in rural areas and relies on agricultural production, so the change in water resources has a strong effect on the livelihood of local inhabitants. Ms H T Le, an officer of the Department of Agriculture and Rural Development of Tinh Bien district, expressed that "*the rain has changed abnormally, prolonged rain or no rain for many days affecting the growth and yield of rice. At the sowing stage, rain may last many days, cause waterlogging, or delays the sowing time. If it rains a lot at the harvest time, the rice will fall over and loses yield" (KIP Interview, 2021)*. It is similar to the study conducted in An Giang noted that the variation of rainfall over the years is the most critical factor affecting rice yield [14].

3.2 Change of agricultural practice and perceptions of water conservation

3.2.1 Shifting of agricultural practices in the rice field. Tinh Bien district is different from other districts in the province due to a series of hilly outcrops, so Tinh Bien is termed a "hilly district ."It is also important to note that hilly is the concept in the context of the plains, not in comparison to the real mountainous regions of Vietnam. The three main sub-agricultural zones of the district are listed as follows:

- The alluvial field is about 20,260 ha (average 2 – 3 m above mean sea level). The area has been built up by sediment from Hau River, which is suitable for rice, aquaculture, and wet forest.
- The highland field is about 8,953 ha (averages 5 – 30 m about mean sea level). The area can grow fruit trees and rice and raise livestock.
- The hilly area comprises about 6,330 ha. This region is suitable for minerals, construction materials, eco-tourism, and resorts due to its many hills and beautiful landscapes.

Viet Nam's national agricultural policy has long strived to increase domestic supplies and exports of rice through intensive production, and this is most apparent in the two delta regions of the Red River in the north and Mekong in the south, where about [32]. Although crops in Tinh Bien are various, rice is the main crop in the district. The information on rice cultivation in Tinh Bien from 2009 to 2019 is described in Table 2. The table shows that the rice areas have changed from year to year, all part of a longer trend in increased production through more intensive cropping following government policy, but without an increase in rice yields, suggesting a sustainability limit has been reached. This significant

increase in rice production, in itself, is putting water supplies across the delta under increasing strain, as most of it relies on both surface water and groundwater irrigation in the dry season (and, to a lesser extent, the wet season), increasing competition for a limited resource and decreases water quality for other ecosystem uses. Rice production jumped markedly between 2017 - 2020 as a result of further construction of irrigation systems, adding to the complex network of existing dykes, dams, pumps, and canals that cover the Delta landscape. People switched from double rice cropping to triple cropping rice since the construction of more high dykes and pumps that isolate the paddy fields from the river channels, thereby theoretically protecting them from flooding but also denying the fields the benefits of floodwater, such as the ingression of sediments and nutrients from the Mekong River.

Table 2. Area, yield, and rice production in Tinh Bien district from 2009 to 2019.

Year	Rice (ha)[a]	Yield (ton/ha)	Production (Ton)
2009	35,069	5.6	197,298
2010	39,190	5.8	228,399
2011	41,513	6.3	261,407
2012	42,068	6.0	254,259
2013	42,932	5.9	251,238
2014	42,188	6.0	254,689
2015	42,244	5.7	239,904
2016	43,388	5.1	223,014
2017	42,212	5.1	216,379
2018	41,989	5.7	240,975
2019	44,181	5.5	244,763

[a]: It is calculated for all crops cultivated in the area year-round.

Source: [21]

In the case of cropping on the hilly slopes above the floodplain, many areas are unsuitable for rice fields due to limited irrigation water availability, so they are mostly dedicated to growing a range of upland crops [33]. The total area converted from rice cultivation to growing vegetables and fruit trees in 2018 was 452.67 hectares; in 2019, up to now is 1,427.26 hectares. Figure 7 shows the range of upland crops grown in Tinh Bien district over the past ten years, with a trend of crops using less water. Cassava is considered a drought-tolerant crop. Others can be listed as peanuts and beans.

In general, it is found that the agriculture of Tinh Bien district is mainly reliant on rice cultivation and, to a lesser extent, the cultivation of upland crops in the few hilly areas. The recent increase in rice production is due to an increase in the area of the third crop of rice. However, the district authorities have decided not to develop more rice cultivation areas due to water and soil limitations but to encourage farmers to switch to crops that consume less water.

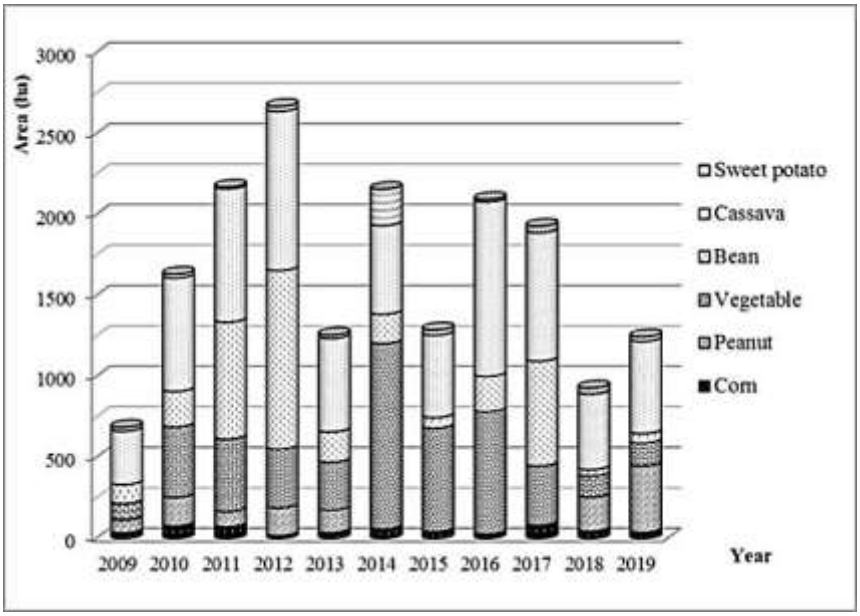

Figure 7. Status of upland crops in Tinh Bien district, including sweet potato and cassava, planted as crops that require less water than rice.

Source: [21]

3.2.2 Some perceptions of climate change effects on local inhabitants. There are some differences in climate risk perception between local officers and farmers. Local agricultural officers are well aware of the overall changes in climate factors and the impacts of water shortage for agricultural cultivation, which differs somewhat from the thoughts of farmers. The perception of one senior agricultural staff on the effects of climate change on rice cultivation is indicated below:

Mr T V Tran, the officer of the Agriculture and Rural Development Department in Tinh Bien District, expressed that the soil texture is poor and that it cannot hold water for a long time together with the influence of climate factors contributes to causing water shortages in the area.

Ms H T Le, an officer of the Cultivation and Plant Protection sub-department in Tinh Bien district, mentioned that the climate has been erratic, and it affects agricultural production.

The perceptions tend to be somewhat different among farmers. The results indicated that farmers' perceptions of climate effects are varied depending on the place where they live and cultivate.

Farmers living in areas with adequate irrigation systems are not aware of changes in water availability, while farmers cultivating in areas without irrigation are well aware of the effects of water shortages in cultivation areas.

Mr. V D Le, a farmer cultivating in the alluvial field, expressed that the water used in rice cultivation is supplied by the water cooperative. Farmers have enough water for their crops.

Mr. N Chau, a Khmer farmer cultivating the highland field, shared that local farmers are facing a severe shortage of water. Rice cultivation mainly depends on the rainy season (using rainwater). Soil is dry, infertile, and difficult to improve. Sometimes, it is abandoned for six months in the dry season.

In Tinh Bien district, rice is and will be continuously considered the main crop. Rice uses a lot of water than other crops, together with some farmers living in well-function irrigation areas, have not been aware of changes to water supply over time. Farmers can use as much as they want. All contribute to causing water supply decreases. Therefore, it is necessary to have adaptive solutions from the government and the people.

3.3 Linkages between local institutional and Farmers' Response

Reacting to environmental changes is not new; farmers have been doing it for centuries, almost since the dawn of history, since the climate is part of the landscape of human habitation [34], [24]. In research about climate risks and adaptation strategies in the Lower Mekong River basin, other authors have indicated that there have been various structural and non-structural adaptation practices occurring at the local level. Most of the structural measures received direct or indirect support from government agencies, while non-structural options have been conducted by local inhabitants [35]. The research has found that both government actors and farmers have responded to the changes in the availability of water resources in Tinh Bien district.

3.3.1 *Building Infrastructure as structural adaptation* As mentioned in the previous part, the water source for rice cultivation in Tinh Bien district is divided into two main eco-regions: deltaic floodplains and several hills. The lowlands get water directly from manmade irrigation canals through pumping stations, and parts of the uplands get water from manmade canal systems, and the majority rely on rainfed agriculture (figure 8).

Figure 8. Canal under construction (left picture) and completed canal delivering water to the rice fields (right picture) in Van Giao Commune, Tinh Bien district.

Figure 8 shows a canal system built to serve intensive rice production. Due to the topography of Tinh Bien district with a lot of sandy soils and poor water retention, cement-lined canal systems have been built to limit water loss during transportation. In terms of irrigation system management, Decision No. 144/QD- People's Committee dated 22/01/2020 of the People's Committee of An Giang province approves the decentralization of management of irrigation infrastructure assets within An Giang province. The water pumping process is managed by different agencies depending on the type of equipment and energy source (electrical pumping stations are managed by district and provincial agencies, while diesel pumping stations are managed by local people). The length of canals in the district is shown in Table 3.

In Vietnam, irrigation schemes are managed by government institutions controlled by the Ministry for Agriculture and Rural Development [28]. Faced with the current climate crisis, to manage water resources, the Department of Agriculture and Rural Development in Tinh Bien district has to coordinate with other state agencies to ensure enough water for agricultural production is supplied, especially during the dry season.

Table 3. The status and levels of the irrigation systems supplying agriculture in Tinh Bien district.

Levels	Managed by	Number of canals	Length of canals (m)	Command area (ha)
Level I Level II (connect district)	Province	10	115,840	5,000
Level II (within a district) Level III (connect commune, within a commune)	District	80	232,188	11,839
Total		90	348,028	16,839

Source: [36]

3.3.2 Farmer's Action as a non-structural Option. Tinh Bien district, farmers have taken many actions to improve their livelihoods by having a more reliable supply of water. They commonly switch to crops that require less water (e.g., cassava, peanut). They choose other rice varieties. The selected seeds are purebred, so farmers can follow one seasonal crop calendar provided by the local irrigation agency. They use more fertilizers to visit the fields regularly to detect pests since some diseases on rice are easy to develop either in wet or dry weather conditions. Two diseases that cause a lot of rice problems are Rice Blast and Sheath Blight has different growing conditions. Rice blast disease caused by the fungus *Pyricularia oryzae* lives well in conditions of cloudy weather, low temperatures from 22-30^{0}C, and high air humidity of 90-95%. At the same time, Sheath Blight disease caused by the fungus *Rhizoctonia solani* grows strongly in higher conditions of temperature around 24-32^{0}C and high humidity. Some households apply drip irrigation for orchards or vegetables. Other farmers dug fond or repaired canals in their farms to store water. However, the number of farmers who have a place to dig a pond or are eligible to maintain the canal to bring water to the field does not account for a large proportion because this requires investment. In addition, the area for ponds does not generate direct income. Therefore, most of the solutions farmers choose are selecting new varieties and techniques. This is also found in other places in Asia, Bastakoti et al. (2014) have found that local practices reflected the improvement in the management of water resources, such as the use of on-farm water management practices like creating farm ponds, rainwater storage, and dredging the field channels [29]. The hope is that the transformation of crop structure shifts to growing more drought-tolerant crops in the district will bring about new and more effective directions in agricultural production for the people, contributing to improving people's lives. Experiences have been noted that in the process of crop restructuring, farmers' action needs the support of the local government for the implementation of measures to be effective [35].

3.3.3 Solutions for better water management. In the district, there has been cooperation between the local state institutions and farmers in responding to changes in water resources. Local institutions have facilitated adaptation in different ways to meet the current needs.

One of the highlights is that the irrigation system has been developed for the difficult areas of the district for irrigation, so many farmers can now access water for cultivation. Advanced irrigation methods have been introduced to some farmers in the area. However, there are still difficulties in operating the pumping system for both farmers and officials. Understanding carefully the current situation for better cooperation is necessary for water resources management in agricultural production. Some recent problems and their solutions are stated in Table 4.

Table 4. Current situation and opportunities for improved water use in Tinh Bien district.

	Situation	Opportunities
a	The terrain of the district has different topography, so water is inevitably hard to distribute equally to all moves from high to low fields (the pumping station should operate continuously to supply enough water for the area for all areas).	There is a need for closer cooperation between officials and farmers. Take advance of the natural topography, water hard to distribute equally to all moves from high to low fields (the pumping station should farmers' fields.
b	Farmers sometimes have to spend more time getting water because the pumping program is not carried out as scheduled,	The pumping plan should be prepared appropriately. When there is a change, it must promptly notify the people.
c	Water-saving irrigation methods (mainly used on fruit trees and upland crops) are costly.	Current water-saving irrigation solutions are costly and not suitable for all farmers. High investment costs will mean they are mostly suitable for better-off households. Opportunities exist to subsidize costs for lower-income households, therefore making them more affordable and widely adopted.
d	Water-saving approaches and technological solutions are not yet common at the community level.	Savings solutions should be applied at the community level to improve water-saving efficiency for a bigger group of farmers. This is something that can be addressed by appropriate development policy and practical strategies.
f	People's awareness concerning the need to conserve water is still low and does not match the urgency of climate change and ecological crisis.	It is necessary to widely disseminate extension advice to the people about saving water approaches, and techniques in farming to both keep up with wider global trends and protect them from the impacts of worsening climate change. This will require appropriate policy support from the government, as farmers are one of the most vulnerable groups to climate change but also are the major water consumptive sector in the delta.

The Climate change crisis has caused increasingly severe and complex effects over time across Southeast Asia, so a more ecologically rational and economical use of water resources for agriculture is essential, both as a major consumer of water also because farmers are at the front line of change and highly vulnerable to its impacts, having implications to wider food security issues. Since rice is still the main crop in the district, the water-saving techniques offer some potential to reduce usage and increase the adaptive capacity of farmers. It provides the ability to reduce and limit water consumption locally and the ability to apply water quantities according to the plant's needs at each stage of growth, limiting excess water but not affecting yield and plant quality. Among new techniques being trialed, the alternative wet and dry technique (AWD) has shown some potential to be useful in water conservation. In rice plantations in An Giang province, farmers adopting AWD realized not only water-saving effects but also improvements in rice yield and growth [37]. AWD is a knowledge-intensive practice for optimizing watering amounts and timing in paddy rice farming. It requires no extra infrastructure, but it does require well-arranged irrigation conditions and additional labor to be effective [38]. However, existing paddy irrigation conditions are a crucial factor influencing whether farmers decide to adopt AWD or not [37]. Paddies suitable for AWD should be carefully considered from the viewpoint of irrigation conditions and present water scarcity. For further study, the criteria for choosing experience

fields should be considered carefully in terms of soil structure, topography, and the current irrigation system. In addition, the role of collective action in facilitating adaptation is a key issue where lessons can be learned from successful interventions and good practices elsewhere [24]. The willingness of the community is essential since local farmers need to understand the benefits and limitations of the technique for it to be accepted at the community and household levels.

4. Conclusion

Climate change and multiple impacts of human-related development, including poorly conceived and implemented hydraulic infrastructure development and excessive groundwater abstraction, have affected agricultural production in the Mekong Delta. Several recent papers have noted that the delta may have reached or be reaching a "tipping point" in terms of its socio-ecological sustainability, and food production systems could be significantly threatened in the future due to a range of anthropomorphic-related causes. Farmers are facing an increasingly uncertain future as combined climate and ecological crises take hold in the region, being felt particularly acutely by smallholder farmers on marginal lands, such as those in the study area. Rice is still the main crop in the district of Tinh Bien, and farmers are heavily dependent on its production, despite it being a significant consumer of water and with relatively low-profit margins. Faced with this situation, the local government and farmers in the region have begun to take action to adapt to these changes. The state's support is mostly structural, mainly through the construction of irrigation systems to carry water to wider areas. However, this infrastructural expansion and redistribution of water can both increase demand, thereby putting additional stress on a limited resource in a time of climate change, but also increase inequalities between individual farmers and user groups. The government, while aware of climate change impacts, both now and in the future, is only beginning to address the multiplicity of problems faced in the complex Delta environment that will require all inhabitants, including farmers, to adapt rapidly in the coming years. Farmers need to be given the tools and education to make wise choices to adapt to change, which must include reducing water consumption and being more ecologically cognizant in their approaches to farming. Local agricultural officers have a vital role to play in raising awareness of farmers about threats posed by climate change and other factors on water resources use; through technological adaptation and resources, use should be enhanced. However, local farmers and officials alike in Tinh Bien district and elsewhere in the Vietnam Mekong Delta need to be facilitated and supported by appropriate policies and practical programs or interventions that focus on the most disadvantaged communities and provide appropriate support that will even up to existing inequalities and allow fair access to water resources for all.

Acknowledgments

We would like to express our thanks to local officers and farmers for their willingness to spend time and share their experiences. Our deepest appreciation to David J H Blake, the project mentor, for advice and communication; thanks also for his English editing. Especially thanks to the Stockholm Environment Institute for financial support to the grant number SEI Work Order No. 100099101, Budget Line 1.1

References

[1] Le A T, Hoang T T, and Vo V N, 2014 *Climate change impacts to livelihood of people in the Mekong Delta. Forum for protecting environmental and culture for sustainable development in the Mekong Delta.* Changing of land use, biological conservation and livelihood of people in the Mekong Delta

[2] CARE 2015 *Study on climate change adaptation livelihoods for the poor with landless & landless* Ha Noi

[3] Entzinger H and Scholten P 2016 *Adaptation to climate change through migration, a case study in the Mekong Delta International migration organisation*

[4] Adger W N, Huq S, Brown K, Conway D, and Hulme M, 2003 Adaptation to climate change in the developing world *Progress in development studies,* vol **3**, no 3, pp 179-195

[5] Minderhoud P SJ, Coumou L, Erkens G, Middelkoop H, and Stouthamer E, 2019 Mekong much lower than previously assumed in sea-level rise impact assessments *Nature Communications* https://doi.org/10.1038/s41467-019-11602-1

[6] Oppenheimer M, B C Glavovic, J Hinkel, R van de Wal, A K Magnan, A Abd-Elgawad, R Cai, M Cifuentes-Jara, R M DeConto, T Ghosh, J Hay, F Isla, B Marzeion, B Meyssignac and Z Sebesvari, 2019 Sea level rise and implications for low-lying islands, coasts and communities. In: IPCC Special *Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]*.

[7] TKK and SEA START RC, 2009 *Water and Climate Change in the Lower Mekong Basin: Diagnosis and Recommendations for adaptation. Water and Development Research Group, Helsinki University of Technology (TKK), and Southeast Asia START Regional Center (SEA START RC),* (Chulalongkorn University. Water and Development Publications, Helsinki University of Technology, Espoo, Finland)

[8] Boretti A, 2020 Implications on food production of the changing water cycle in the Vietnamese Mekong Delta *Global Ecology and conservation* vol 22 june 2020 DOI: https://doi.org/10.1016/j.gecco.2020.e00989

[9] Le A T, Wyseure G, Viet L and Haest P J, 2004 Water quality management for irrigation in the Mekong River Delta, Vietnam *Paper presented at the International Conference on Agricultural Engineering, AgEng2004, Leuven, Belgium. Paper proceeding*

[10] Department of Environment and Natural resources, 2017 Water resource in the Mekong Delta, threats and solutions for effective use to achieve sustainable development *Paper presented at the Conference of sustainable and climate resilience development of the Mekong Delta of Vietnam Can Tho, September 26-27, 2017*

[11] Bui D T, 1985 *Hydrological characteristics of An Giang province* (Vietnam: An Giang Science and Technology Committee Publishing)

[12] Statistical Office of An Giang Province, 2019 *Statistical Yearbook of An Giang Province* [Online] Available: http://www.sciepub.com/reference/244939

[13] Le X T, 2017 Floods and sediments on the Mekong Delta *Proceedings of the Science conference on Agricultural Production in terms of flood and alluvial changes in the Mekong Delta June 27, 2017* (Vietnam: An Giang University)

[14] Nguyen T M H, Tran V T, Huynh V T M and Van P D T, 2012 Evaluation of the influence of hydro-meteorological factors and agricultural production on rice yield in the low-dyke area An Giang province *Journal of Science Can Tho University* no 23a pp 165-173

[15] Vo D T and Ho T N, 2015 Impact of abnormal floods on rice production in Vinh Phuoc commune Tri Ton district An Giang province *An Giang University Scientific Journal* no 8 pp105-113

[16] Department of Natural Resources and Environment in An Giang, 2021 Environmental protection planning for An Giang Province in 2020 *Report on the current state of the environment in An Giang province in the period 2016 – 2020* pp 12

[17] People Committee of An Giang Province, 2017 Perspectives on the development orientation of the upper provinces of the Mekong Delta in the context of climate change *Paper presented at Sustainable development model transformation in the Mekong Delta to adapt to climate change, Can Tho, September 26-27*

[18] Map of Chau Doc city (2021, 1 July) *Map of Chau Doc city* [Online] Available: http://angiang.ban-do.net/2018/01/thanh-pho-chau-doc.html Access 14/06/2021

[19] Anh Le T, Cottrell A and King D, 2018 Using comparative historical analysis to compensate shortcomings of cross-sectional methods in explaining causal mechanisms: Lessons from a study of rice farmers in Vietnam *International Journal of Development and Sustainability* 2018; vol **7** pp 1914-1935

[20] Tinh Bien web, (2021, 14 July) *Natural condition and natural resource* [Online] Available: http://bit.do/tinhbien Access 14/06/2021

[21] Statistic yearbook of Tinh Bien district, 2019 *Statistical office of Tinh Bien district* [Online] Available:https://www.citypopulation.de/en/vietnam/admin/an_giang/890__t%E1%BB%8Bnh_bi%C3%AAn/
[22] Intergovernmental Panel on Climate Change 2007 *Impacts, Adaptation and Vulnerability* Contribution of Working Group II to the Fourth Assessment Report of the IPCC (978 0521 88010-7 Hardback; 978 0521 70597-4 Paperback)
[23] Adger W N, 2003 Social capital, collective action, and adaptation to climate change *Derklimawandel* vol **79** no 4 pp 327-345
[24] Barry S and Olga P, 2001 Chapter 18 Adaptation to climate change in the context of sustainable development and equity *Report of Intergovernmental Panel on Climate Change (IPPC)* (USA: Soussana APaJ-F) p 36
[25] Intergovernmental Panel on Climate Change, 2001 *Working Group II: Overviews of Impacts, Adaptation and Vulnerability to climate change* [Online] Available: https://www.ipcc.ch/report/ar6/wg2/
[26] Smit B, Burton I, Klein, R J and Street R, 1999 The science of adaptation: a framework for assessment *Mitigation and adaptation strategies for global change* vol **4** no 3-4 pp 199-213
[27] Luu V N and Nguyen M G, 2017 Climate characteristics of An Giang province *Journal of Meteorology and Hydrology* no 12
[28] Harris D N, 2006 Water management in public irrigation schemes in Vietnam *Australian Centre for International Agricultural research* no 43
[29] Nguyen B V, 2009 Factors affecting the sustainability of three rice crop production in the Mekong Delta *An Giang Science & Technology Magazine* No. 06/2009 ISSN 1859 – 0268
[30] Park E, Ho, HL, Tran, D D, Yang, X, Alcantara, E, Merino, E and Son, V H, 2020 Dramatic decrease of flood frequency in the Mekong Delta due to river bed mining and dyke construction *Science of the Total Environment* 723 (March 2020): vol https://doi.org/10.016/j.scitotenv.2020.138066
[31] Brown P R, Tuan V V, Nhan D K, Dung L Cand Ward J, 2018 Influence of livelihoods on climate change adaptation for smallholder farmers in the Mekong Delta Vietnam *International Journal of Agricultural Sustainability* vol **16** no 3 pp 255-271
[32] Mekong River Commission (2021, 14 July) *Agriculture and irrigation* [Online] Available: https://www.mrcmekong.org/our-work/topics/agriculture-and-irrigation/
[33] Le P D, 2017 Solutions to development the Mekong Delta under natural and human stresses *Paper presented at the Conference on sustainable and climate change resilience development of the Mekong Delta of Vietnam Can Tho, September 26-27* (2017)
[34] Agrawal A and Perrin N, 2009 Climate adaptation, local institutions and rural livelihoods *IFRI Working Paper* (University of Michigan: School of Natural Resiurces and Environment) pp 350-367
[35] Bastakoti R C, Gupta J, Babel M S and Van Dijk M P, 2014 Climate risks and adaptation strategies in the Lower Mekong River basin. *Regional environmental change* vol **14** no 1 pp 207-219
[36] Management Board of Tinh Bien Electric Pumping Stations 2020 *Report of summarizing the implementation of tasks in 2020 and planed in 2021*
[37] Yamaguchi T, Tuan L M, Minamikawa K and Yokoyama S, 2019 Assessment of the relationship between adoption of a knowledge-intensive water-saving technique and irrigation conditions in the Mekong Delta of Vietnam *Agricultural water management* vol 212 pp 162-171
[38] Yamaguchi , Luu M T, Minamikawa K and Yokoyama S 2017 Compatibility of alternate wetting and drying irrigation with local agriculture in An Giang province, Mekong Delta, Vietnam *Tropical Agriculture and Development* vol **61** no 3 pp 117-127