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Resilience of various innovative water management practices: The case of rice production in the Vietnamese Mekong Delta floodplains

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A R T I C L E I N F O

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A B S T R A C T

The floodplains play an important role in agricultural development and rural livelihoods in the Vietnamese Mekong Delta. As an intensive rice production area of Vietnam, the floodplain has experienced significant changes in water management regime during the recent decades. Depending on specific locations and irrigation infrastructure investments, four main water management practices have been innovated, particularly a planting season of two crops per year (2C1Y), three crops per year (3C1Y), three years eight crops (3Y8C) and two years five crops (2Y5C). The 4R framework (Reform, Result, Resilience, and Return) was developed based on grounded theory approach for resilience assessment of various innovative water management practices. In terms of resilience, we found that each crop pattern involves pros and cons, and the intensive crop practices are less resilient systems, especially in social, environmental, and ecological aspects. The findings provide good lessons learned not only for Vietnam but also for the other rice-producing deltas implementing ecosystem resilience to adapt to global challenges such as flood, drought, and salinity intrusion.

1. Introduction

Water is a limited resource and increasingly scarce in the context of climate change and population growth. By 2050, global food production will increase by 60–100% compared to 2005 and water demand for energy, industry and domestic needs will also increase by 55% within the same period (IWMI, 2019). Agriculture involves the largest consumption of water amongst all sectors. Global agricultural food production has already consumed approximately 70% (up to 80% in Africa and Asia) of all water withdrawn from rivers and aquifers (UNCTAD, 2011; Grafton, 2019). Irrigated agriculture is considered one of the success stories of the 20th century. Innovative water supply solutions have helped increase crop yields and enabled farmers to grow more crops per year which has enhanced food security. But the expansion of irrigated areas have drastically decreased natural wetlands and as well the cropping intensities have resulted in water pollution and land degradation due to excessive chemical fertilizer and pesticide application which have chronically that damaged the ecological system and destroyed biodiversity (CIP-UPWARD, 2003; Levidow et al., 2014; Colosimo and Kim, 2016; World Bank, 2017; IWMI, 2019). In addition, climate change can negatively impact water resources which will influence agriculture and food production. Global temperature rise may also consequence in hotter dry seasons and wetter rainy seasons in some areas, greater uncertainty and increased risk of more extreme and frequent floods and droughts (UNCTAD, 2011; Cosgrove and Loucks, 2015). Such changes will affect agricultural and ecosystems, which in turn can adversely impact people's livelihoods, particularly in the wetland and lower delta areas (Smajlg et al., 2015; Tanner et al., 2015).

The Vietnamese Mekong Delta (VMD) is located downstream of the Mekong River, the twelfth longest river and the second richest river basin in terms of biodiversity in the world and its topography is characterized as fertile alluvial floodplains with a tropical monsoon climate (Xuan and Matsui, 1998; Tuan et al., 2007). Naturally, from July to December, about 1.2–1.9 million ha (30–48% of the total VMD area) in the upstream and middle areas is inundated due to the overflow from the Mekong River and local rainfall, whereas in the dry season, extensive areas along the Delta's coastlines experience salinity intrusion (Tuan et al., 2007; Binh, 2015). This water regime allows farmers to cultivate

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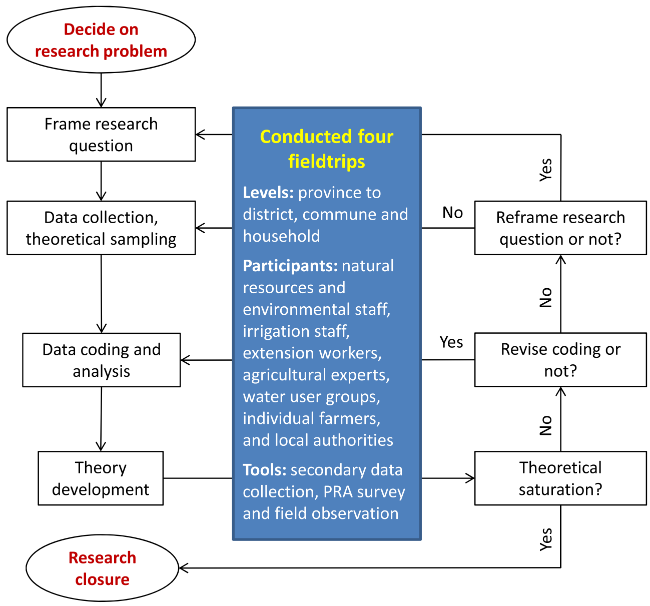


Fig. 1. The iterative and adaptive process of grounded theory applied in the research
(Based on Bitsch, 2005 and Creswell, 2013).

only one rice crop per year. As a result, the growth of agriculture in the 1980s did not keep up with the population growth, causing food shortages and extreme poverty (Binh et al., 2021). To ensure national food security, the Vietnamese Government invested in many large irrigation works for rice production. Thanks to irrigation development, Vietnam shifted from being a food importer in the 1980s to producing enough food for domestic consumption as well as becoming one of the world's leading rice exporters today (Ut and Kajisa, 2006; Binh et al., 2021). According to USDA (2021), Vietnam exported 6.2 million tons of rice in 2020, accounting for 14% of the total rice export volume in the world market, ranking it as the second largest rice exporter globally after India. Up to 90% of Vietnam's rice exports come from the VMD, while this region accounts for only 12% of the country's area and 20% of the country's population (GOV, 2017; GSO, 2020).

The investment in irrigation works in the VMD floodplains enables farmers to increase the rice cultivation from 2 to 3 crops per year, even in many areas, up to 7 crops within 2 years. This intensification increases rice production but creates huge environmental costs due to the heavy use of fertilizers and pesticides (Chapman et al., 2016; Chapman and Darby, 2016; World Bank, 2017; Minh et al., 2020). Besides, the VMD is also predicted to be one of the most affected deltas by climate change globally (IPCC, 2007; IMHEN and UNDP, 2015). In addition, the construction of hydropower dams and irrigation infrastructures in the upper countries of the Mekong River results in alterations of the natural river flows, which decreases sediment supply from the river, leading to an increased need for chemical fertilizer application as compensation to maintain soil fertility (Chapman et al., 2016; Chapman and Darby, 2016). All these factors affect the sustainable production and livelihood of local people. To adapt to these new conditions, it is necessary to have innovative water solutions to promote sustainable development. Recently, local authorities have made changes in water management towards reducing the intensive levels (i.e., shifting from 3 rice crops per year to 5 crops over 2 years) in some floodplain areas of the VMD, particularly in An Giang province.

Many scholars and international institutions recognized that innovative water management practices occurred in agriculture worldwide, but assessment of such innovations is still a challenge (UNCTAD, 2011; IICA, 2015; Colosimo and Kim, 2016; IWMI, 2019). Cosgrove and Loucks (2015) stressed that many innovations in sustainable water management involve high risk and may incur uncertain returns. According to IWMI (2019), enhanced water resources management and more resilient water services are essential for adaptation to the adverse impacts of climate change and for strengthening the resilience of communities, ecosystems, and economies. In other words, *how can water management make agricultural development more resilient under high risk and uncertainty?* This paper aims to answer the above question by examining various innovative water management practices for rice production in the North Vam Nao (NVN) irrigation system, which is situated in An Giang floodplain province of the VMD. Lessons learned from this study can benefit other rice-producing deltas globally in informing long-term adaptation strategies.

2. Methodology

2.1. Application of grounded theory

The grounded theory is defined as a qualitative method used to build a theory or an analytical framework for further research. The result was achieved through a process of working and interacting continuously with many people to understand the study phenomenon (Bitsch, and Creswell, 2005, 2013). Therefore the theory or framework is derived during the process of implementation and further developed based on actual data and information from the ground. The grounded theory research process consists of several steps as depicted in Fig. 1.

The process begins with the problem identification and research question formulation. The next step is sample selection and data collection. Sample selection in the grounded theory is theoretical sampling or non-probability sampling. That is, the selection of the observation sample or the interviewee cannot be determined in advance in a statistical way but is very "flexible" based on the actual situation and the researcher's judgment so that the collected data will reflect the actual nature of the research phenomenon (Corbin and Strauss, 1990; Charmaz, 2006). After data collection, the data undergoes coding and analysis. According to Bitsch (2005)), the coding and analysis of field data applies the method of constant comparison; that is, after each interview or observation the data must be coded and compared in order to recognize the commonalities and differences. By this method, the data will be classified and sorted into categories and sub-categories to see the correlation between them in order to explain the phenomenon being studied in the most appropriate way (Leedy and Ormrod, 2015). Concepts are then recognized and theory or framework will thus be formed. This process ends only when data and information are saturated, meaning that further data collection and analysis will not generate new ideas (Corbin and Strauss, 1990). If the information is not saturated, researchers will revert back to the data collection and analysis step, and adjust the research question to suit the actual context as necessary.

As described by Creswell (2013), the grounded theory research is an "iterative and adaptive" process: collect data at the field, return to the office for analysis, then go back to the field for further data collection, return to the office for the second analysis, and so forth. The process will be continued until there is sufficient data and information to build a theory. Application of this approach, we conducted 4 fieldtrips during November 2019 and April 2021 in An Giang province for data collection by using some participatory tools (i.e. historical analysis, seasonal calendar, in-depth interviews, and focus group discussion), to discuss with various peoples at different levels about livelihood and ecosystem resilience of rice production in different models of water management. Thanks to the advantages of grounded theory approach, a novel framework was developed demonstrating how the relationship between water reform policies or practices with its result, resilience and return (the so called 4R framework) can be used for assessing various water management regimes within other contexts. Additionally, we also interviewed researchers and scientists in the VMD and Ho Chi Minh City who have good knowledge and experiences in the region to assess the resilience by different water management practices. Details of the process are described in the next sections.

2.2. Site selection and description

An Giang province was selected for this study because being situated within the VMD floodplains (Fig. A.1), it has a diverse practice of various water management regimes, including innovative water management that can be used as case studies for comparison. According to GSO (2020), An Giang rice production in 2019 reached 3.9 million tons, ranking at the second position among 63 provinces in Vietnam placing it as one of the major food producers in the country. Data show that the planted rice areas in An Giang continuously increased from 453.2 thousand ha in 000t581.2 thousand ha in 2010 and 632.4 thousand ha in 2020 (Table A.1). This result was achieved through investment in irrigation infrastructure to prevent floods which facilitated crop extensification and intensification. However, such investments occurred unevenly amongst districts in the province. Depending on the level of investment and water management regime, two main dike systems exist in An Giang. The high-dike or full-dike system can prevent both early and late floods with higher water levels and is suitable for 3 rice crops per year, referred to as Winter-Spring (WS), Summer-Autumn (SA) and Autumn-Winter (AW) respectively. The low-dike or semi-dike system could only protect more interior areas from the early floods and allow water to enter the fields during the late floods and therefore 2 rice crops per year (WS and SA) are dedicated these areas. For this study, we selected two districts (An Phu and Phu Tan) each with different water management regimes and cropping patterns and explored how different innovative water management practices influenced the livelihood resilience of local residents.

An Phu district has a total area of 226 km^2 and a population of 148.5 thousand inhabitants, which is equal to a population density of 656 people per km^2. An Phu represents low dike areas that are dominating by the two rice crops per year. Table A.1 shows that the third rice crop (AW) area in 2010 was only 0.9 thousand ha, accounting for 3% of the total cultivated area. By 2020, the AW area grew up to 5.5 thousand ha, but it still accounted for a relatively low 16% of the total cultivated area in the district.

Phu Tan district covers an area of 313 km^2 with 188.8 thousand inhabitants, which is equal to a population density of 604 people per km^2. Phu Tan represents the high dike areas, where a system of dikes has been constructed since 2002 thanks to the joint Australian and Vietnamese government NVN water control project. As a result, total rice planted area in Phu Tan increased remarkably from 49.7 to 66.9 thousand ha between 2000 and 2010 before declining to 60.2 thousand ha in 2020 (Table A.1). The variation of total planted rice area was caused mainly by the change in AW crop due to recent changes in water management practice.

In short, the two districts had more or less the same condition before 2000. Since then, Phu Tan was benefited from the NVN project which allows farmers to grow more crops (due to an increased area of AW crop). Recently, the AW crop in Phu Tan has decreased whereas the AW crop in An Phu steadily increased. These trends provide a good case study for comparison of different innovative water solutions for agricultural development and livelihood resilience.

2.3. Data collection

Both secondary and primary data were collected in An Giang province between November 2019 and April 2021. The secondary data were gathered from various sources, particularly from the Department of Natural Resources and Environment (DONRE), the Department of Agriculture and Rural Development (DARD), the Department of Labors, Invalids and Social Affair (DOLISA), the Statistical Office at provincial and district level, and annual socio-economic reports at communes. Such secondary data provide a general overview on socio-economic and environmental situation including hydrology, weather, land use, water management, irrigation infrastructure, agriculture, aquaculture, poverty, population, and pollution. The primary data were collected through four fieldtrips by using some Participatory Rural Appraisal (PRA) tools such as timeline analysis, seasonal calendar, focus group discussion, key informant interview, in-depth interview, and observation at the sites (FAO, 2011). A total of 88 participants were involved in the survey; of which, 73 persons were residents of An Giang province and 15 persons were scientists from Can Tho and Ho Chi Minh cities (Table A.2).

2.4. Data analysis

Collected information and data were analyzed using the grounded theory approach (Bitsch, 2005; Creswell, 2013; Leedy and Ormrod, 2015). According to Leedy and Ormrod (2015), there are three main steps in data analysis applied grounded theory which are summarized below.

- ***Open coding:*** The data are divided into segments and then scrutinized for commonalities that reflect general categories. In fact, raw data in the form of field notes gathered from the survey were documented in MS-word and broken into single word or phrases in Vietnamese. These pieces of information were used for coding. Based on the codes, they are grouped into four categories namely Reform, Result, Resilience and Return. After meaningful categories are identified, the data are further examined for properties or subcategories that characterize each category. For example, the Reform category consists of various information such as cropping pattern shift, crop yield fluctuation, flood regime change, irrigation development, dike investment, sediment reduction, etc. Those were organized into reform context, reform process and reform content sub-categories. This process was done manually on MS-Excel sheet.
- ***Axial coding:*** During the process of open coding, one or few categories might emerge as being central to the investigated phenomenon. In axial coding, one of these categories is selected as a core category. This core category serves as an axis around which certain other categories appear to revolve in some way. In this study, we did not use multivariate analysis to outline core categories. Instead, the four identified categories were organized in cause-effect relation, making connections between categories to discover regularities, variations and singularities in the data.
- ***Selected coding and theory development:*** A single category is selected as the core concept in the phenomenon, and a theory or new framework is developed based on this concept and its interrelationships with other categories. In this case, Reform of water for rice development is selected as the starting point to assess resilience among different innovative water management practices. The reform created different results that may have resulted in numerous resilience outcomes. Such outcomes provided copious lessons learned and policy implications that were identified as discussion themes for the next round. Therefore, the analytical framework is structured logically from Reform to Result, Resilience, and Return categories. Quantitative data collected during the survey from local statistic offices and related departments are also employed to supplement and confirm the qualitative approach.

In addition, through the grounded theory approach, it was necessary to distinguish resilience by different levels because water reform in the research sites may bring positive outcomes for local communities but affect others at a larger scale. In this study, we consider the cross – scale interaction of the complex delta system by assessing livelihood and ecosystem levels of resilience. The assessment of ecosystem resilience allows a better understanding of the long-term effects of innovative water management, but it may be difficult to observe resilience at the household level. Therefore, within this context, livelihood resilience has been assessed through five livelihood capitals such as human, natural,

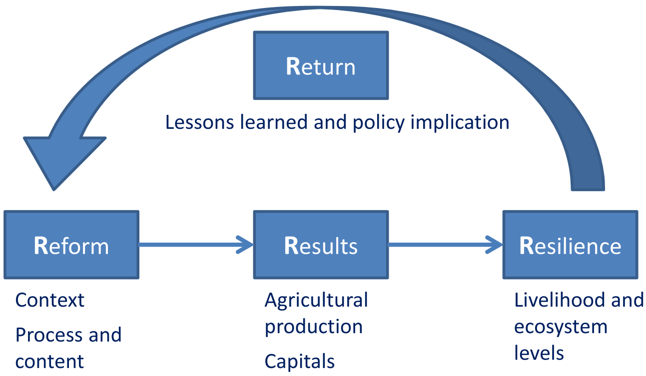


Fig. 2. The 4R framework for assessment of innovative water management.

physical, financial, and social according to the Sustainable Livelihood Approach (DFID, 1999; Uy et al., 2011). Ecosystem resilience is characterized by four dimensions of sustainable development namely social, economic, environmental, and institutional (Wass et al., 2011; Tanner et al., 2015). To get more scientific figures, the livelihood resilience and ecosystem resilience for each water management scheme were assessed by expert's opinions. Fifteen scientists from local research institutes and universities who are experts on the field of rice production and irrigation development in the Mekong delta were asked to "quantify" both resilience levels. For example, to assess livelihood resilience, the research team went to meet respondents separately and asked them to score each livelihood capital for a particular water management practice from low (1 point) to medium (2 points) and high (3 points) based on their expertise. They were also asked the reason for scoring. Total scores of livelihood resilience are calculated as an average of all resilience dimensions according to the experts' opinions. The ecosystem resilience was also evaluated using the same approach.

Application of such above steps, the assessment of innovative water management framework is created as Fig. 2. The information and data are classified into four categories consisting of Reform, Result, Resilience and Return (so called 4R framework). Each category contains sub-categories to characterize the category's meanings. For example, the reform category has three sub-categories as context, process and content of water reform in the study site. In this 4R framework, water reform is a core concept but related to result, resilience, and return that will be presented and discussed in the next sections.

3. Results and discussions

3.1. Reform – as an innovative water management practice

Generally, reform means to change something in a positive direction, typically a social, political, economic or institutional practice. Reform in water sector is defined as an ongoing process in response to crises in relation to water quality and water availability (Grafton, 2019) or water reform requires perseverance, continuity, and long-term commitment from governments to ensure that water resources are managed sustainably to meet changing community needs (Australian Government, 2017). In this study, reform refers to any changes (soft or hard measures) to make sure that water is managed more sustainably in response to risk

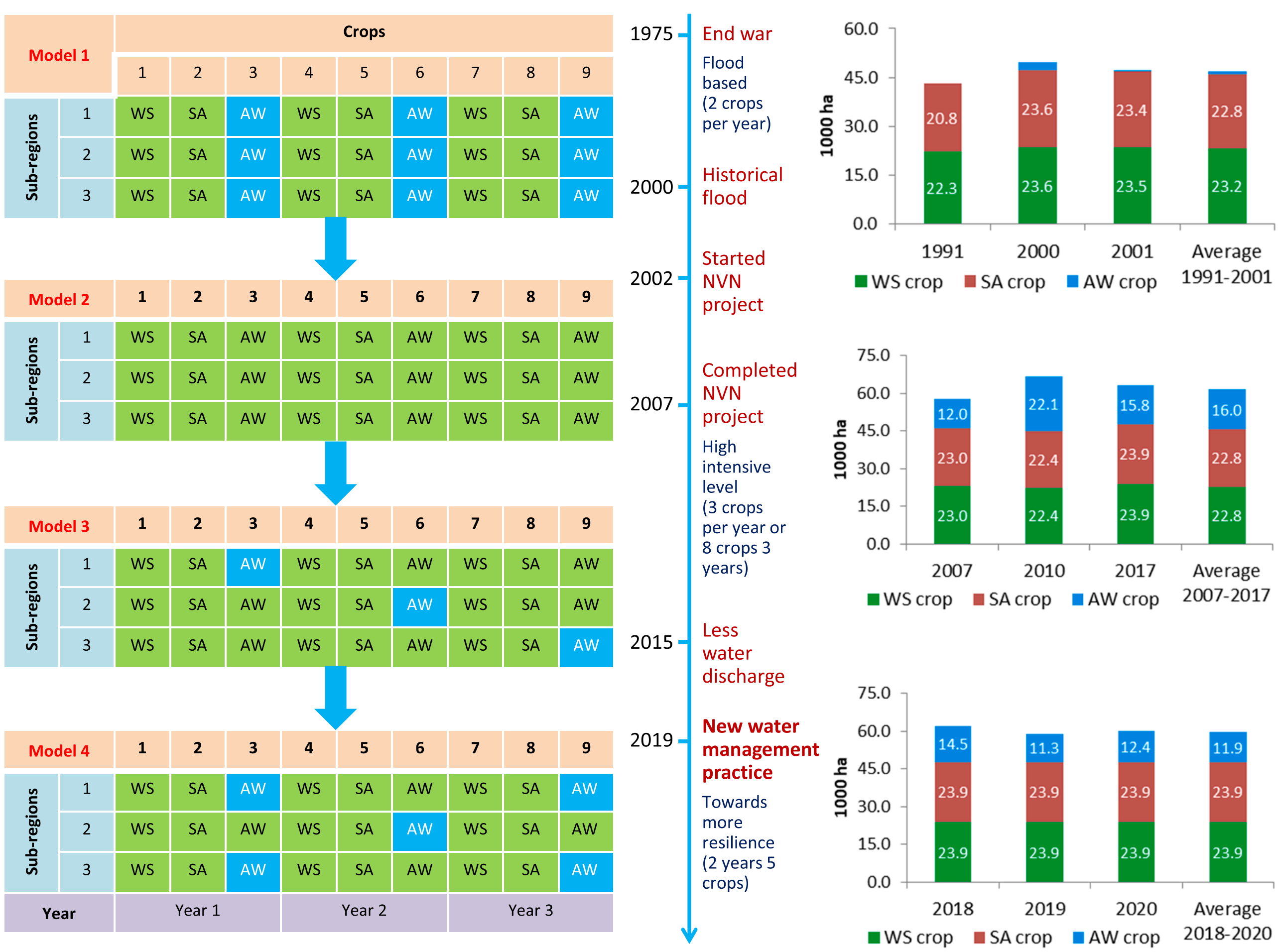


Fig. 3. Timeline analysis of innovative water management in Phu Tan district, WS, SA, AW are Winter-Spring, Summer-Autumn, and Autumn-Winter crop; AW with blue background means fallow crop in flooding period.

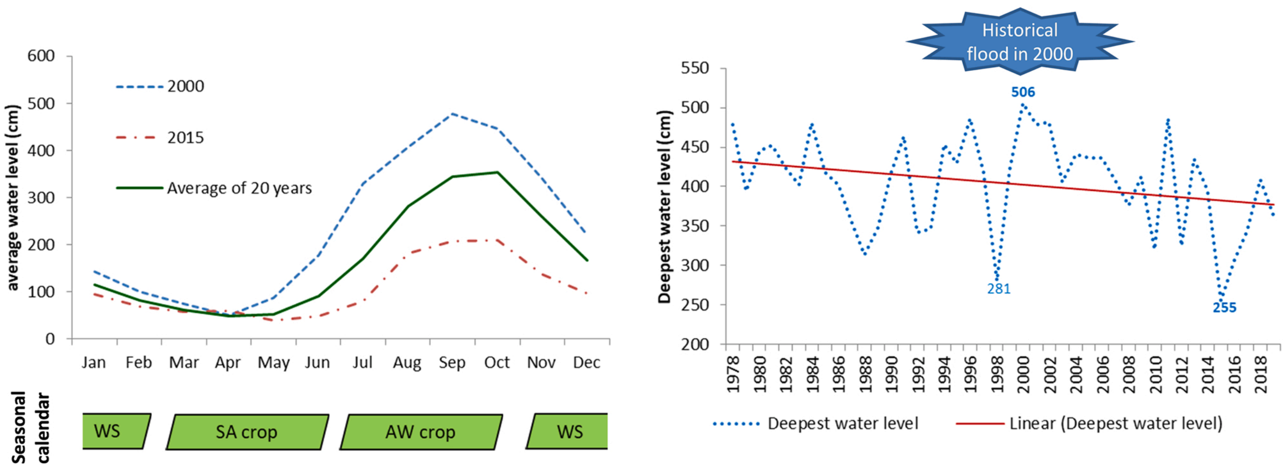


Fig. 4. Seasonal calendar and water level in An Giang province (at Tan Chau station) (data sources: National hydro-meteorological station).

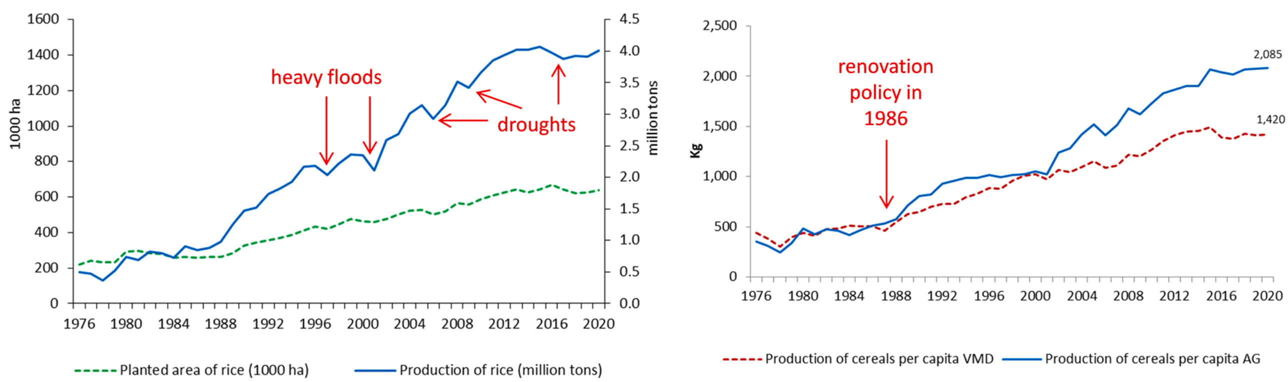


Fig. 5. Cereal production development in An Giang compared to the VMD in the period of 1976 – 2020.

and uncertainty context and to meet community needs. For example, construction of a canal or a dike to control flood (hard adaptation) or reduction of crops per year to deal with water flow fluctuation (soft adaptation) is considered as water reform or an innovative water management practice. Viewed in this perspective, water reform in An Giang has a long history. Since 1819 Vinh Te canal (next to Cambodian border) had been dug for multi-purposes as national security, agricultural production and navigation. However, active reform in water sector was recently implemented, particularly after the historical flood in 2000 but it varied place to place based on community needs and resources. Fig. 3 summarizes the context, process and content of water reform in Phu Tan district, An Giang province. The reform process has a strong relationship to crop development. Since 1975, the cropping pattern has been evolving through four different innovative water management models.

Model 1 – a natural flood-based practice for two crops per year (2C1Y): After country reunification in 1975, the government had accelerated the rice production to lift people from the poverty and ensure food security for local people. However, limited resources did not allow the district invest on big irrigation. Fig. 3 depicts that total rice planted area in Phu Tan increased from 43.2 thousand ha in 1991–49.7 thousand ha in 2000. The increase of rice area was mainly due to farmers expanding the area of SA and AW crops in favorable lands that were at high elevations and/or near canals. The historical flood in 2000 dropped the rice planted area to 47.1 thousand ha one year after, mostly by reduction of AW crop. Exposures to annual floods have placed the AW crop production at risk, which are prone to very uncertain conditions such as extreme floods (Fig. 4). High dike development was therefore accelerated to control flooding in the district which enabled farmers to shift into a new cropping model.

Model 2 – Flood prevention for rice intensification with three crops per year (3C1Y): There were some investments for flood control in the VMD after the extreme flood in 2000. In An Giang province, the NVN water control project started in 2002 and was considered as an innovative water governance initiative to demonstrate the economic, social and environmental benefits in the floodplains through a coordinated water and land management approach, according to the key informant interview with DARD in 2020. The project consists of a 100 km ring-dike with 16 major sluice gates and 39 culverts along the ring-dike covering an area of 30,836 ha of natural land (of which 24,039 ha agricultural land) located mainly in Phu Tan (88%) and Tan Chau (12%) districts. The areas are divided into 24 compartments or sub-regions; each ranges from 300 to 2500 ha depending on canal and inner dike networks (Data collected at DARD in 2020). This well-designed system provides a flexible water management for crop production at each sub-region. The NVN scheme enables farmers to grow more crops as the AW crop is protected from floods. Consequently, planted rice areas increased dramatically following the project completion in 2007 and reached a peak in 2010 with an area of 66.8 thousand ha in Phu Tan district (Fig. 3). In 2010, the cultivated area in each crop (WS, SA or AW) was more or less the same meaning that the level of rice intensification has increased and the 3C1Y model (or even a frequency of 7 crops over 2 years) was popular this time. After some years, both the local authorities and farmers realize the disadvantages of intensive farming (loss sediment, water pollution, land degradation, wild fish reduction, and pest and disease outbreak), so they subsequently reduced the level of intensification and changed their strategy by adopting another model of water management.

Model 3 – Flood control for lower intensification with three years eight crops (3Y8C): Since 2010, there was a change in cropping system from the 3C1Y to 3Y8C. As visualized in Fig. 3, the 3Y8C model means that

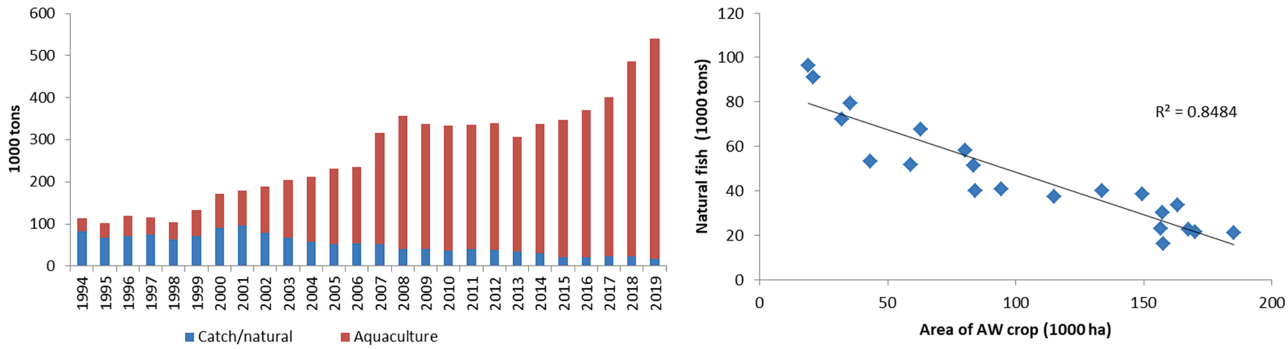
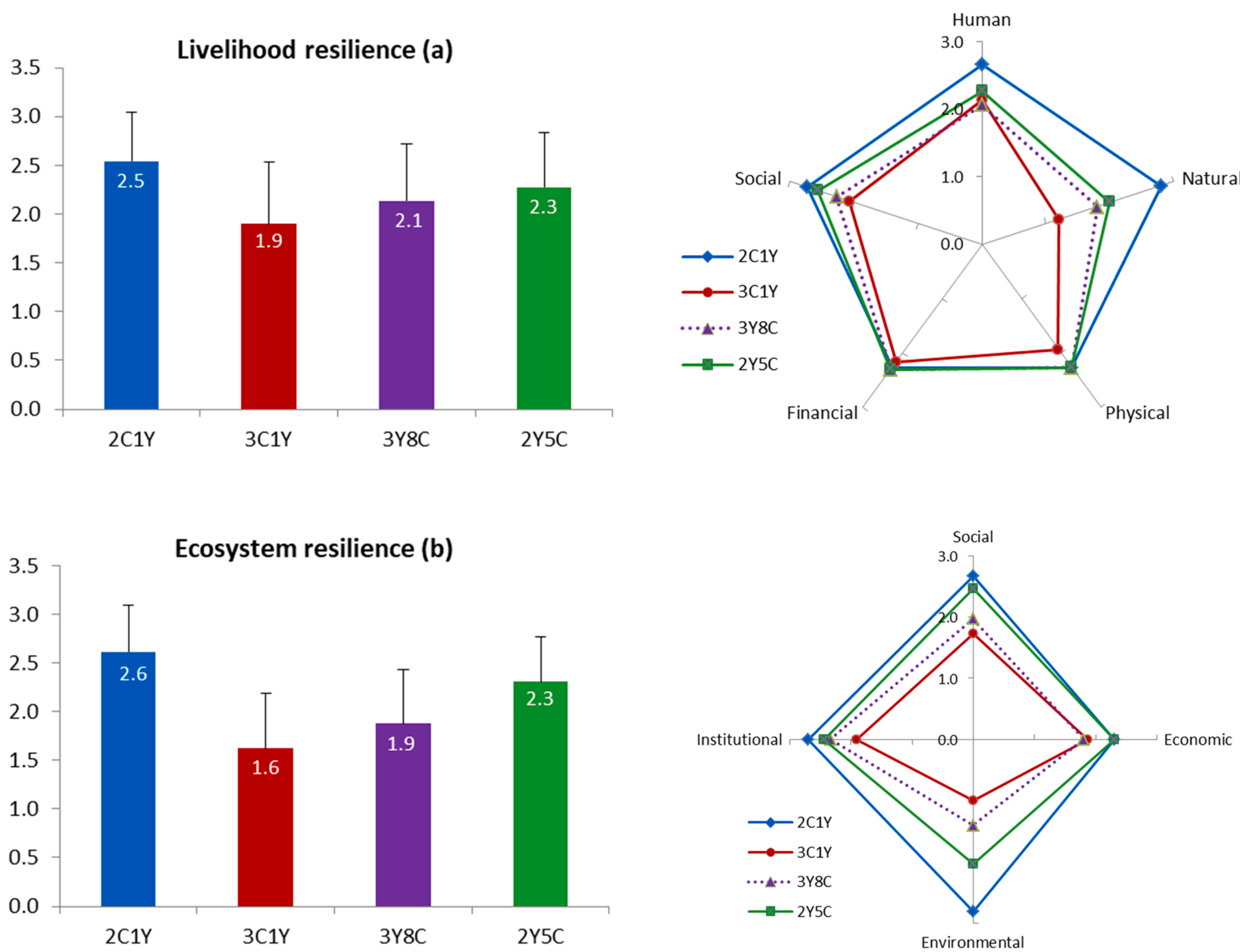


Fig. 6. Fishery development and relationship between catch production and area of AW crop in An Giang province.



(Based on expert interview with 15 scientists; scoring from 1 = low, 2 = medium, and 3 = high)

Fig. 7. Resilience and its dimensions by different water management models for rice production, *(Based on expert interview with 15 scientists; scoring from 1 = low, 2 = medium, and 3 = high)*.

two consecutive years of doing triple crop pattern, then only double crops (WS and SA) are cultivated in the third year, also called 3–3–2 model. The land keeps fallow during the flood season (AW crop) in the third year to get sediments and water to wash the fields. It is noted that this flood discharge practice is not applied to the entire NVN area but rotated for each sub-region as shown in Fig. 3 to ensure food production annually. As results, the AW crop area dropped down from 5000 to 6000 ha in Phu Tan district per year after 2010. Although the lower intensive level agriculture model was applied, the 3Y8C is not really effective. This is due to the water level in the flooding season being lower (Fig. 4) during that period and amount of sediment also decreased due to the impact of hydropower dams in the upstream of the Mekong River. These factors caused lower rice yields and resulted in farmers applying more agro-chemicals to compensate. Therefore, there was a need for water management strategies to adapt to a new situation and cropping patterns in the district shifted yet again to another model.

Model 4 – Flood control towards more resilience with two years five crops (2Y5C): The new water management practice for model of 2Y5C has been applied since 2019. This model is characterized as follows: in a particular sub-region, farmers applied double crops in the first year,

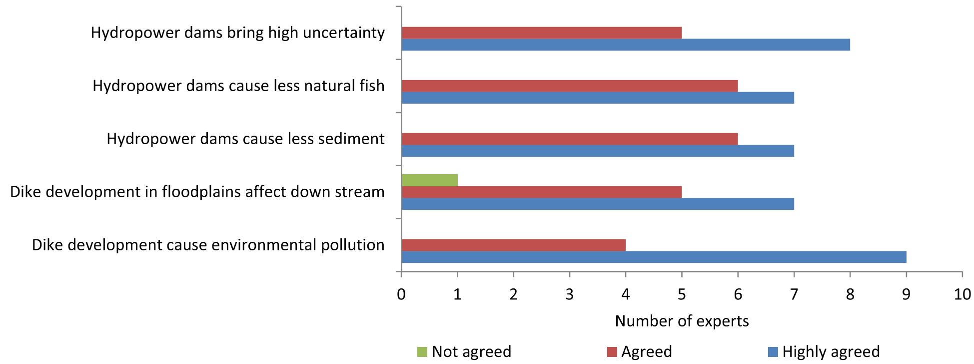


Fig. 8. Expert opinions on impacts of hydropower and dyke development in the Mekong delta.

triple crops in the second year and so forth as illustrated in Fig. 3. By application of this new practice, the AW crop area in Phu Tan district has declined about 10,000 ha compared to 2010.

In An Phu and some other districts, the hard measures were also constructed after the NVN project. The result was that, the AW crop areas in An Giang continued to increase up to the present day; for example, from 21.0 thousand ha in 2000–115.0 thousand ha in 2010 and 171.8 thousand ha in 2020 (Table A.1 and Fig. 5). In other words, the water reform took place differently leading to different results and resilience outcomes that will be discussed in the next parts.

3.2. *Results – a growth in food production and livelihood capitals*

The water reform process has gone through many stages since 1975 in An Giang province that have resulted in changing the food production system and livelihood capitals of local communities. Data collected from the An Giang Statistical Office shows that rice planted areas increased 2.9 times, from 217.6 thousand ha in 1975–637.2 thousand ha in 2020 while rice production grew with a higher level (8.0 times) from 0.5 million tons to 4.0 million tons in the same period. Therefore, rice yields increased continuously, from 2.2 tons per ha in 1975–6.3 tons per ha in 2020. Results also show that food development in general and rice in particular in An Giang and the VMD increased rapidly after the government's renovation policy in 1986 (shifting from central planning to market orientation) (Binh et al., 2021). However, the growth in An Giang was the most rapid amongst the VMD provinces, especially after 2000 as a result of innovative irrigation practices that were implemented to control flooding. Consequently, production of cereals per capita in An Giang exceeded that of the VMD overall average; for example, 2085 kg per capita produced in An Giang compared to only 1420 kg in all of the VMD in 2020 (Fig. 5).

Besides rice development, fishery production in An Giang has also grown rapidly in recent years. The province's fishery production has increased from 114 thousand tons in 1994–540 thousand tons in 2019, equivalent to an increase of 474% of fishery production in the past 25 years. It is noted that the growth of fishery production is mainly due to the rapid increase in aquaculture, while the wild catch decreased drastically. Fig. 6 shows that the catch production in 1994 accounted for 72.4% of total fishery production, but this share decreases substantially to only 3.0% in 2019. Farmers and local authorities believe that the decrease in natural fishery production is mainly due to the increase in crop production, causing loss of habitat for aquatic species in the flood season. Indeed, there is a strong inverse correlation between catch production and the planted area of AW rice crop in An Giang (Fig. 6). Similarly, Thieu and Dung (2014) reported that there were five major drivers affecting natural fishery production in An Giang including population growth, destructive fishing tools, dike development, pesticide use and decline in Mekong river discharge. They also found that the income structure of the poor who relied on natural fish has changed towards a reduction of fishing income, especially for those fishing inside the dike system. In fact, income from catch/natural production declined from 62% to 28% of total income for insiders in the period of 2003–2012 whereas it declined from 65% to 46% for outsiders in the same period (Thieu and Dung, 2014).

Changes in crop and fishery production systems also change community livelihood capitals. Statistical results in Table A.3 show that some financial capital indicators in An Giang such as gross output per hectare of cultivated land, monthly income as well as GDP per capita have continuously increased over the years. The increase in financial resource promote the increase of other capitals such as human capital (i.e. enrolment rate of general education, number of doctor per 10,000 inhabitants, or rate of malnutrition of children under-5-years old), physical capital (i.e. housing condition, access to electricity, clean potable water or adequate sanitary systems) and social capital (i.e. number of agricultural cooperatives or a decrease in multi-dimensional poverty). However, natural resource, especially fisheries catch production, has continuously decreased over the years; for example, wild fish catch has decreased from 42.5 kg per capita in 1994, to 15.0 kg in 2014 and only 8.6 kg in 2019 (Table A.3).

In short, the water reform process has created different cropping patterns, achieving several positive results such as ensuring food security and socio-economic development in An Giang province in the last 3 decades. However, whether these achievements are stable or resilient in the long term is another matter, especially considering the large-scale interaction of the floodplain and coastal areas of the delta in the context of climate change, sea level rise, and water flow changes from the upper Mekong River. This will be discussed under analysis of resilience in the following part.

3.3. *Resilience – distinguish between livelihood and ecosystem resilience*

Resilience has become a focus of international development agendas and an important criterion for measuring the development potential of individuals, communities or socio-ecological systems that is increasingly applied in many studies regarding water related hazards, agriculture, fishery and rural livelihoods (Uy et al., 2011; Nyamwanza, 2012; Speranza et al., 2014; UNISDR, 2004; Tanner et al., 2015; Zhou et al., 2021; Gong et al., 2020; Everard and West, 2021; Poelma et al., 2021). Each of the above authors has their own resilience definition. In this study, resilience refers to the capacity of a system potentially exposed to floods to adapt by changing in order to reach and maintain an acceptable level of functioning and structure (based on UNISDR, 2004). As mentioned, it is necessary to distinguish resilience by different levels; for example, at household/livelihood resilience and at a larger scale within the landscape/ecosystem context which will be discussed below (Fig. 7).

3.3.1. *Livelihood resilience*

Fig. 7a presents the results of expert interviews on livelihood resilience of 4 different water management schemes for rice production in An Giang based on five livelihood capitals. The results show that the 2C1Y model has the highest resilience (average of 2.5 points with STDEV of 0.501), followed by the models of 2Y5C (average of 2.3 points with STDEV of 0.559), 3Y8C (average of 2.1 points with STDEV of 0.584) and 3C1Y (1.9 points with STDEV of 0.631). The 3C1Y model is considered as the lowest resilience, of which all five livelihood capitals have lowest results compared to the other models. Table A.4 shows that, although the 3C1Y model has the highest productivity (16.6 tons/ha/year) and total revenue (96.1 million VND/ha/year) but the financial efficiency is the lowest (only 0.57) due to high production costs, especially high costs for fertilizers and pesticides. The high level of fertilizer and pesticide application pollutes the environment, reduces wild fish catch yields, and adversely affects the health of people. The score on human capital is therefore low. In addition, the intensive farming and mechanization in the 3C1Y model also affects the livelihoods of the poor, since they rely on aquatic species in the flood season for income or protein sources or engage in labor for manual rice harvesting. These contribute to low social capital scores in the 3C1Y model. In contrast, the 2C1Y model has the highest financial efficiency (0.99) as well as the best fertilizer efficiency (1 kg of fertilizer for 16.7 kg of rice) which results in the model being assessed as the most optimal in the livelihood resilience score. The 3Y8C and 2Y5C models have intermediate values between 2C1Y and 3C1Y.

3.3.2. Ecosystem resilience

Similar to the resilience at the household level, the ecosystem resilience is highest for the 2C1Y system, followed by the 2Y5C and 3Y8C. The most intensive rice production, the 3C1Y, has the lowest resilience scores according to the expert interviews (Fig. 7b). The 2C1Y is the most extensive rice production before shifting to intensive rice production models and is considered as providing the highest social, institutional and environmental benefits. The innovation 2Y5C that farmers switched to recently has lower environmental benefits compared to 2C1Y, however, is reasonable in terms of institutional and social perspectives compared to 3C1Y and 3Y8C models. For the 3C1Y model, all resilience dimensions are perceived lower than other production models, of which the environmental component is the lowest. The negative impacts of intensive rice production on the environment are well recognized in literature (Minh et al., 2019; Yokoyama et al., 2015). It is necessary to highlight that while the economic resilience of 3C1Y is the same as other production models, the economic benefits at the ecosystem level are lower than other production models. This indicates that the costs of intensive rice production may be higher at the community than at the household level and when taking these costs into account, the economic resilience of intensive rice production was not promising as previously anticipated at the household level. The 5C2Y, although having the same economic resilience as the 2C1Y, it has lower environmental resilience than the previous one. It is understandable since the 2C1Y model is considered as providing the highest ecosystem benefits to soils, water, and biodiversity (Chapman et al., 2016; Nguyen et al., 2019).

While experts express consensus on a high resilience regarding environmental capacity at the ecosystem level of the 2C1Y model compared to the others, especially the 3C1Y model, environmental parameters from different sources confirmed the situation (Table A.5). A study in 2019 shows that although the water quality index of aquatic life in the semi-dike area (2C1Y) is higher than the full-dike area (3C1Y), they were both categorized as poor in the dry season (5.40 and 3.70, respectively). This parameter improves for both models during the wet season; nevertheless, it is still poor for the 3C1Y (4.7) while upgraded to moderate quality for 2C1Y (7.10) (Minh et al., 2019). Similarly, the number of fish species found in rice fields in 2018/2019 in the semi-dike is 1.7 times higher than in the full-dike area (Quang et al., 2019). This is consistent with the result from another study in 2010 with the Average Score Per Taxon of BMWP-Vietnam where 2C1Y scores 3.13 (fair level) and 3C1Y scores 2.44 (poor level) (Thuan et al., 2010). The water quality for both models at the ecosystem scale has not improved after a decade. In terms of average weight of sediment accumulated, the 2C1Y model receives 5 times more sediment weight than the 3C1Y model (22.5 and 4.4, respectively). Consequently, the amount of total nitrogen of sediment and the total phosphorus of sediment in the 2C1Y model is higher than the 3C1Y 9.6 and 4.5 times, respectively. Similarly, total potassium of sediment in the 2C1Y model is higher than the 3C1Y model by 2.8 times (Phung et al., 2017). The 2C1Y model increases the sediment supply for the soil, and as a result reduces the amount of fertilizers used compared to the 3C1Y model. This is proven by the amount of chemical fertilizers used in the 2C1Y model which is 2.2 times lower than the 3C1Y model. In addition, the amount of pesticides and gasoline for irrigation in the 2C1Y model is also lower than the 3C1Y model which resulted in lower soil, water, and air pollution levels in the 2C1Y model. As well, this translates to lower expenditures in fertilizer costs.

Comparing An Phu district (considered as less intensive agriculture as it mostly implements the 2C1Y model) and Phu Tan district (considered as more intensive agriculture implementing the 3C1Y model), quantitative data revealed that rice production in Phu Tan decreased sharply in an extreme flood event during 2011 and recovered slowly while rice production in An Phu was relatively unaffected (Fig. A2). This suggests that the degree of resilience of the intensive model is relatively lower than the other models. In addition, the more intensive model required greater water consumption. In fact, if water requirement in WS, SA and AW are 8080; 7520; and 6500 m^3/ha/crop respectively (Nhan et al., 2007) then the 2C1Y model in total would consume about 15,600 m^3/ha/year compared to 22,100 m^3/ha/year for the 3C1Y; 19,933 m^3/ha/year for the 3Y8C; and 18,850 m^3/ha/year for the 2Y5C. Therefore, the 2C1Y practice facilitates more freshwater conservation which in turn is very beneficial for communities a long or closer to the coastal areas as they are affected by a lack of freshwater supply during the dry season, which is exacerbated by hydropower development in upstream countries.

The resilience assessment at the community level demonstrates that resilience is higher with less intensive rice, mostly due to an increase of environmental, social, and institutional aspects of resilience. This implies that the shifts to less intensive crop as observed recently could rapidly increase the environmental and social resilience and to a lesser extent improve institutional and economic resilience. These changes may have multiple dimensions, and the impact on one resilience aspect may be compensated or compromised by others. For example, shifting to less intensive rice will improve production efficiency, however, but unfortunately will also reduce labor demand and thus less employment opportunities (for example, the 3C1Y model requires 803 h/ha per year, while the 2C1Y is about 323 h/ha) (Nhut, 2008). More solutions are therefore needed to effect more optimal approaches.

In general, there are some differences in terms of resilience at livelihood and ecosystem levels among four water management schemes; for example, in the 3C1Y model, the scores of livelihood resilience are higher than that for ecosystem resilience (1.9 points compared to 1.6 points). The 3C1Y model may bring higher incomes to rice farmers, but damages the environment and causes social inequality at the ecosystem level and in the long term. Data from the Household Living Standard Survey in An Giang clearly reveals that income gaps between the richest quintile and the poorest quintile increase from 7.0 times in 2008–8.4 times in 2018. Anyhow, both show the highest resilience in the model of 2C1Y and declining by 2Y5C, 3Y8C and 1Y3C respectively. Hence, there are many lessons learned for policy implication to expand effective water management model in the future considering not only at household level but also ecosystem level which will be discussed in the Return part below.

3.4. Return – discussing lessons learned and policy implication

The Return aspects of the 4R framework are presented by reflecting on some lessons learned and future policy implication for improving resilience.

The NVN water innovation system has shown some policy implication aspects that have both positives attributes and some limitations. As discussed in the reform section, the improved governance structure, enhancing the role of participation and collaboration, and facilitating local leadership are key achievements observed from the project. In addition, the farmers expressed feelings of reassurance in food security, safety and stable cultivation all of which has proved to be significant advantages of the system. These positive aspects for the NVN are included in both official legislation and standard procedures. However, this innovation in resilience has yet to be expanded to other areas in An Giang province and in the Mekong delta. For example, another commune in An Phu district, upstream of NVN project is covered by a high dike system but adequate water supply that meets requirements is rare. Rather, groundwater extraction (in abundant surface water areas), land degradation, water pollution, and misuse of water resources are typical problems in these areas. It has been observed that the key successful factor of the NVN project is the involvement of international donors, such as AusAID, in designing and supporting the implementation of the project (Tran et al., 2020).

Next, from the water innovation perspective (Wehn and Montalvo, 2018; WWAP, 2016), the NVN system has significantly contributed to water infrastructure development and water supply. However, the system fails to link with regional water management (e.g., impacts of upstream and downstream water resources) (see Fig. 8). The system has a limited capacity to adapt to the changes of water flow from the upstream of the Mekong Delta. Water flushed out from the system may produce pollutants that can harm downstream ecosystem. The benefits (e.g., ecosystem services) and the costs (such as the sediment reduction, biodiversity losses, and land degradation) of the system have not been assessed holistically. Contributions of ICT-based innovation[1] could be the next steps for improving the NVN system. Improvement of sediment loss to the NVN areas is another measure. In the Red River Delta of Vietnam where almost all the downstream areas are equipped with high dike to protect the region from flooding and salinity intrusion, a large amount of inorganic and organic fertilizers are applied to maintain soil fertility. Diversification of farming system, together with the improvement of agronomic measures (e.g., introduction of new varieties) and irrigation and drainage systems have helped the delta maintain its functions under low sediment supply from the river (Morton, 2020; Tu et al., 2019). Other solutions such as reservoir management and forest conservation require basin-scale changes that go beyond the household or community levels (Vinh et al., 2014). The NVN as well as the VMD is controlled by both upstream river discharge and downstream tidal effects. The tidal river management from Bangladesh delta (Seijger et al., 2019; Adnan et al., 2020) could be a reference for improving sediment management practice in the Mekong Delta given its innovative features designed for a congested river delta such as improvement for livelihoods and sustainability.

The NVN project is mostly focusing on water management and food security issues in the areas. Livelihood of local people is still rather limited as shown in the resilience section. The project has impacted unequally to different farmer groups such as negatively impacting livelihoods of people whose livelihoods have been based on fishery activities (Thong and James, 2017). This may also lead to the loss of traditional fishing culture (Baran et al., 2007) as well as local biodiversity. In addition, the dominant rice – based livelihood still does not significantly improve the living conditions and incomes of farmers (Tran et al., 2021). The design of the NVN system has some limitation in diversifying cropping system in the areas, which limits farmers in adopting new crops that would be more suited to market – driven agricultural product lines. Thus, the water management should be incorporated with agricultural transformation and diversification to promote and ensure the livelihood sustainability of local farmers (Tran and Weger, 2017; Dung et al., 2018; Tran et al., 2019; Binh et al., 2021). Effective land use planning could be one of the key solutions to link water management with livelihood sustainability (Quan et al., 2020).

[1] Examples ICT – based innovations include improved forecasting systems for floods and drought; smart sensors to reduce water consumption in households, business and municipalities; asset management; demand management; water reuse; and energy saving

4. Conclusions

Assessing (improved) resilience of agriculture development under high risk and uncertainty is very challenging. In this study, based on the grounded theory approach, we presented a novel 4R framework (Reform, Result, Resilience and Return) for the resilience assessment of four dike-based (innovative) water management schemes for rice crop production development over the three decades in An Giang, one of the upper floodplain provinces of the Vietnamese Mekong Delta. We have argued that a water management scheme decoupling with intensive rice production can strengthen the resilience of communities because this production and water management scheme requires less inputs, brings more natural benefits, and has less impacts to the ecosystems. Our findings have revealed that the more intensive crop patterns are also the less resilient systems. Regarding four rice models associated with four water management schemes, the rice model of two crops in one year (2C1Y) is most optimal given its social, economic, and environmental sustainability, while the intensive triple-rice cropping pattern (3C1Y) is overall, and in the long term, more harmful and also undermines the benefits of floods. Other so-called innovative water management schemes, i.e., 8C3Y and 5C2Y, have some improvements but they both seem only to be temporary measures. Our findings have implied a need to support agricultural transformation, for example from rice intensification to less intensive or flood-based farming systems to improve agricultural sustainability and resilience. In addition, this study assessed the resilience of farming systems and the associated communities based on the proposed criteria (capitals). The resilience of each farming system or community to specific stressors (flooding, change of upstream water or fluctuation of market drivers) would be different. Further works could continue to explore this framework for other crops at different places and scales across the floodplains of the Mekong delta, and for specific climatic and non-climatic stressors. These will more clearly delineate their relationships in enabling delta-wide sustainability, strategies and engaging institutional dimensions of governance to assess the validity and duplicability of the 4 R framework.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

See in Fig. A.1, Fig. A.2.
See in Table A.1, Table A.2, Table A.3, Table A.4, Table A.5.

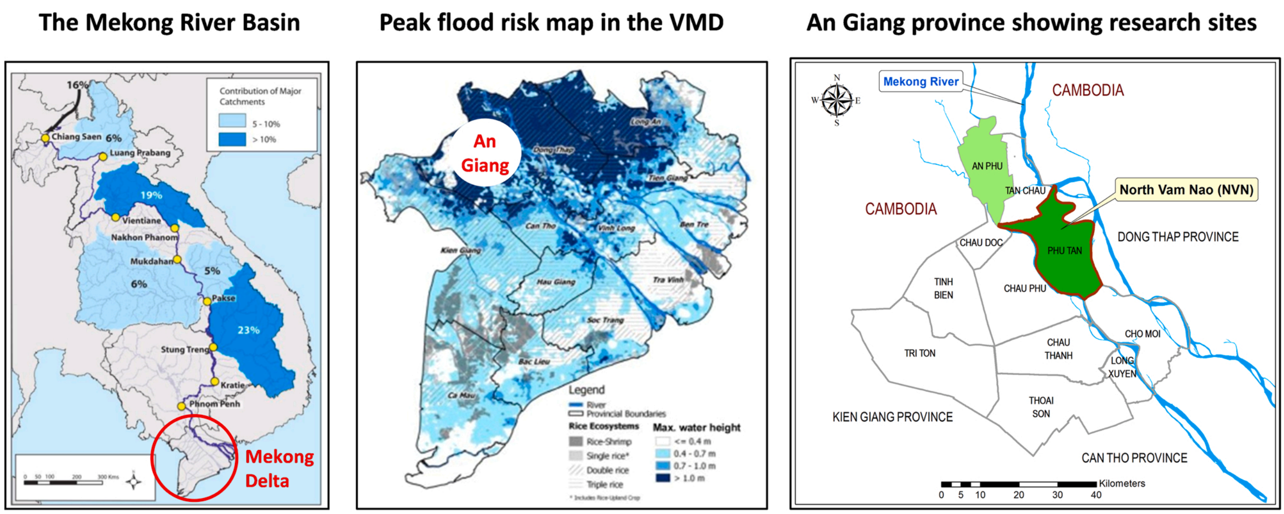

Fig. A. 1. Map showing the study sites in An Phu and Phu Tan districts, An Giang province (Sources: Based on Wassmann et al., 2019; MRC, 2020).

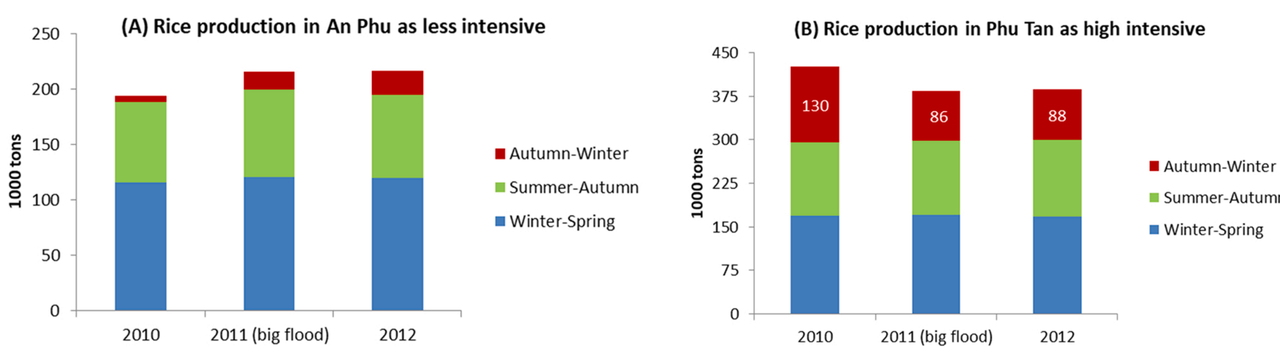

Fig. A. 2. Comparison of rice production after water extreme in An Phu and Phu Tan districts, An Giang province (Sources: Based on secondary data collected in the research sites).

Table A.1
Total land area, population and rice planted areas in the study sites.

Items		An Phu district			Phu Tan district			An Giang province		
		2000	2010	2020	2000	2010	2020	2000	2010	2020
Rice planted areas (1000 ha)	Winter-spring	12.5	15.2	14.1	23.6	22.4	23.9	220.4	234.2	229.4
	Summer-autumn	11.5	13.7	13.2	23.6	22.4	23.9	211.8	232.0	231.2
	Autumn-winter	2.4	0.9	5.5	2.5	22.1	12.4	21.0	115.0	171.8
	Total	***26.4***	***29.8***	***32.8***	***49.7***	***66.9***	***60.2***	***453.2***	***581.2***	***632.4***
Sharing of rice planted areas by crops (%)	Winter-spring	47.3	51.0	43.0	47.5	33.5	39.7	48.6	40.3	36.3
	Summer-autumn	43.6	46.0	40.2	47.5	33.5	39.7	46.8	39.9	36.6
	Autumn-winter	9.1	3.0	16.8	5.0	33.0	20.6	4.6	19.8	27.1
	Total	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***	***100***
Total land area (km^2)		–	–	226	–	–	313	–	–	3537
Total population (1000 person)		–	–	148.5	–	–	188.8	–	–	1907
Population density (person/km^2)		–	–	656	–	–	604	–	–	539

(Sources: Based on AGSO, 2001; AGSO, 2011, AGSO, 2021)

Table A.2
Number of participants involved in the survey at different levels.

Level	Stakeholders	Number of participants
Province	An Giang Department of Natural Resources and Environment	3
	An Giang Department of Agriculture and Rural Development	7
	An Giang Department of Labors, Invalids and Social Affair	3
	An Giang Farmers' Union	1
	An Giang Women' Union	2
District	An Phu and Phu Tan Department of Natural Resources and Environment	4
	An Phu and Phu Tan Department of Agriculture and Rural Development	8
Commune	Local authorities at commune level	11
Grassroots	Leaders of water user group	2
	Farmers	32
Scientists	Research institutes, universities in Can Tho and Ho Chi Minh city	15
	Total	**88**

Table A.3
Results in livelihood capitals in An Giang province between 1994 and 2019.

Capitals	Indicators	1994	2002	2010	2012	2014	2016	2018	2019
Financial	Gross output of cultivated area (million VND per ha)	–	–	85	102	111	119	131	136
	Monthly income per capita (million VND)	0.19	0.26	1.32	1.87	2.47	2.89	3.60	3.84
	Gross domestic product per capita (USD)	–	–	809	1096	1323	1510	1790	1946
Human	Enrolment rate of general education (%)	–	–	77.1	–	–	87.8	89.9	90.0
	Numbers of doctor per 10,000 inhabitant (person)	–	–	4.3	4.3	4.5	7.1	8.2	8.6
	Rate of under-5-year malnutrition (%)	–	–	17.0	15.2	13.1	11.9	12.3	11.7
Physical	Households having temporal house (%)	72.8	47.3	11.0	8.5	5.3	2.6	1.1	1.0
	Households access to electricity (%)	20.6	83.4	93.2	96.1	99.3	99.5	99.1	99.5
	Households access to hygienic water (%)	–	–	92.5	94.0	96.8	97.0	98.1	98.7
	Households access to hygienic toilet (%)	–	–	60.7	70.0	78.0	84.4	88.4	89.2
Social	Numbers of agricultural cooperatives	0	86	105	110	120	127	128	130
	Multi-dimensional poverty rate (%)	–	–	9.2	8.7	8.2	7.6	5.7	4.9
Natural	Production of natural fish per capita (kg)	42.5	38.0	17.5	18.5	15.0	10,7	12.0	8.6
	Area of natural land per capita (m^2)	1748	1633	1666	1702	1747	1789	1831	1854

(Source: Calculated from secondary data)

Table A.4
Financial and fertilizer efficiency of different cropping patterns in An Giang province.

	Cropping patterns for rice production			
Items	2C1Y	3C1Y	3Y8C	2Y5C
A. Total costs (million VND/ha/year)	***32.78***	***61.08***	***51.65***	***46.93***
1. Land preparation	3.04	5.19	4.47	4.12
1. Seeds	3.71	6.12	5.31	4.91
1. Plant protection	7.26	11.35	9.99	9.31
1. Chemical fertilizers	8.18	17.71	14.53	12.95
1. Irrigation	2.94	4.00	3.65	3.47
1. Harvest	4.55	7.13	6.27	5.84
1. Labors	2.84	8.25	6.45	5.55
1. Others	0.26	1.33	0.97	0.79
B. Total revenues (million VND/ha/year)	***65.26***	***96.12***	***85.76***	***80.59***
1. Productivity (tons/year)	13.48	19.63	17.56	16.53
1. Price (VND/kg)	4843	4895	4883	4876
C. Total profits (B-A) (million VND/ha/year)	***32.49***	***35.04***	***34.12***	***33.66***
D. Financial efficiency (C/A)	***0.99***	***0.57***	***0.66***	***0.72***
E. Chemical fertilizers (kg/ha/year)	***805***	***1742***	***1429***	***1274***
F. Fertilizer efficiency (kg rice/kg fertilizer)	***16.7***	***11.3***	***12.3***	***13.0***

(Source: Calculated from PRA survey in An Phu and Phu Tan districts)

Table A.5
Some related environmental parameters in the full-dike and semi-dike systems in An Giang province.

Parameters	Semi-dike (2C1Y)	Full-dike (3C1Y)	Sources
Water quality index of aquatic life in the dry season*	5.40	3.70	Minh et al. (2019)
Water quality index of aquatic life in the wet season*	7.10	4.7	Minh et al. (2019)
Average Score Per Taxon of BMWP-Vietnam**	3.13	2.44	Thuan et al. (2010)
Average weight of sediment (tons/ha/year)	22.5	4.4	Phung et al. (2017)
1. *Total nitrogen of sediment (tons N/ha/year)*	*135*	*14.1*	Phung et al. (2017)
1. *Total phosphorus of sediment (tons P_2O_5/ha/year)*	*45*	*10.1*	Phung et al. (2017)
1. *Total potassium of sediment (tons K_2O/ha/year)*	*363*	*129*	Phung et al. (2017)
Number of fish species found in rice fields in 2018/2019	36	21	Quang et al. (2019)
Chemical fertilizers (kg/ha/year)	805	1742	Table A.4
Pesticides (litter/ha/year)	38	66	Nhut (2008)
Gasoline for irrigation (litter/ha/year)	4.5	14.0	Nhut (2008)

*Rating scale for water quality index of aquatic life: 10–9 for high quality, 9.5–9.0 for good quality, 9.0–7.0 for moderate quality, below 7.0 for poor quality (Minh et al., 2019);
* *Rating scale for water quality based on Average Score Per Taxon of Biological Monitoring Working Party-Vietnam standard (BMWP-Vietnam): 10.0–8.0 for excellent, 7.9–6.0 for good, 5.9–5.0 for moderate, 4.9–3.0 for fair, 2.9–1.0 for poor and 0.0–0.9 for very poor (Thuan et al., 2010).

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