Pragmatic economic valuation of adaptation risk and responses across scales Case study in Vietnam

Working Paper No. 185

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Le Ngoc Lan, Armando Martínez-Valle, Louis Parker, Clement Bourgoin, Nguyen Thi Than, Nora Guerten, Godefroy Grosjeans, Pham Anh Hung, Vu Cong Lan, Vuong Thuc Tran, Pham Quang Ha, Dao Van Thong, Luong Huu Thanh and Peter Läderach

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Abstract

Vietnam is one of the countries particularly vulnerable to climate change. Increased temperatures, increased salinity intrusion due to sea-level rise and altering precipitation patterns significantly affect livelihood options of smallholder farmers, resulting in losses in agricultural production. These impacts are projected to become increasingly severe, hence, adaptation to climate change and sensitivity needs to be assessed and adaptation measures taken. This study provides a vulnerability assessment based on the results for exposure, sensitivity and adaptive capacity. This includes present and projected future climatic conditions and hazards, crop suitability analyses and socioeconomic assessments on a district scale. In addition, a case study is presented focusing on the two provinces of Tra Vinh and Ben Tre, identified as highly vulnerable in the Mekong Delta area. The case study shows opportunities, economic trade-offs and barriers of adoption of climate-smart agriculture (CSA) practises to adapt to progressive climate change.

Keywords

Adaptation to climate change; vulnerability assessment; crop suitability; socioeconomic analysis; climate-smart agriculture; cost-benefit analysis; adoption opportunities and barriers; Vietnam.

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List of abbreviations

AMD	Adaptation in the Mekong Delta project
ASAP	Adaptation for Smallholders Agriculture Programme
CBA	cost benefit analysis
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CIAT	International Center for Tropical Agriculture
CSA	climate-smart agriculture
CSA-RA	climate-smart agriculture – rural appraisal
DAPA	decision and policy analysis
DARD	Department of Agricultural and Rural Development
DONRE	Department of Natural Resources and Environment
FAO	Food and Agriculture Organization of the United Nations
GCM	global climate model
GDP	gross domestic product
GHCN	Global Historical Climatology Network
GHG	greenhouse gas
GSO	General Statistics Office of Vietnam
HH	household
IAE	Institute for Agricultural Environment
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
IRR	internal rate of return
MONRE	Ministry of Natural Resources and Environment
MRD	Mekong River Delta
NIAPP	National Institute of Agricultural Planning and Projection
NPV	net present value
RCP	representative concentration pathways
RRD	Red River Delta
USLE	Universal Soil Loss Equation
VBARD	Vietnam Bank for Agriculture and Rural Development
VBSP	Vietnam Bank for Social Policies

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1. Introduction

Vietnam is one of the countries that have been hardest hit by climate change (ISPONRE 2009). It consists of an extensive coastline, two major river deltas – Red River Delta (RRD) and Mekong River Delta (MRD) – and mountainous areas on its eastern and north-eastern borders. Agriculture lies at the very heart of Vietnam's rural development strategy. The agricultural sector has considerable influence on national economic growth and the status of poverty and malnutrition. Climate change, particularly in the forms of changes in precipitation and temperature, are increasing the risk of floods, soil erosion, typhoons and droughts. Rising sea levels further exacerbate flooding in the deltas and coastal areas (ISONRE 2009). Salinity intrusion is becoming more serious, threatening agricultural production in the delta areas, especially in MRD and making river water inadequate for agriculture (Ha et al 2012). Changes that affect the agricultural sector may affect economic growth and the distribution of incomes for the whole country (Tran 2011).

The International Fund for Agricultural Development (IFAD), under its ongoing Adaptation for Smallholder Agriculture Programme (ASAP), is calling for the prioritization of investments for small-scale agriculture in the most vulnerable areas to climate change. ASAP is a "multi-year and multi-donor financing window targeted at mainstreaming adaptation to climate change into IFAD projects and programmes. ASAP aims at scaling-up successful tried and tested approaches and combine them with innovative processes and tools." This includes: (i) a robust risk assessment; (ii) the replication of multiple-benefit approaches that increase productivity while reducing climate-related risk, (iii) enabling smallholder farmers to access climate finance. Since 2013, ASAP has supported Vietnam in tackling problems of climate change through "Adaptation in the Mekong Delta program" (AMD). The initial three years of the program have been utilized for seeking for research supports from multiple actors and organizations to develop and to reach the expected outcome.

Within this context, the International Center for Tropical Agriculture (CIAT) through its Decision and Policy Analysis (DAPA) research area has implemented "Pragmatic economic valuation of adaptation risk and responses across scales", with the objectives of: (1) assessing the vulnerability of crops spatially and economically; (2) highlighting and prioritizing climate-smart agriculture (CSA) practises by considering the costs and benefits of the practises and characteristic of users to better understand opportunities and barriers of adoption. The project was funded by IFAD/CCAFS Learning Alliance, contributing to its overall aim of enabling agricultural development policy makers and practitioners to make science-based decisions in the context of climate change, leading to greater positive impacts on target populations. The project was carried out in three countries where IFAD's ASAP implementation is most advanced: Vietnam, Uganda and Nicaragua. In Vietnam, CIAT implemented the project in collaboration with several partners from government institutions including National Institute of Agricultural Planning and Projection (NIAPP), Institute of Agricultural Environment (IAE) and AMD project coordination units in Tra Vinh and Ben Tre.

This Working Paper presents results of the project in Vietnam, divided into two chapters: (1) a vulnerability assessment and (2) challenges, opportunities and trade-offs of CSA adoption with the case study in Tra Vinh and Ben Tre.

Chapter 1 starts with a brief overview of the agricultural sector in Vietnam, to explain the rationale of selection of crops for vulnerability assessment. The following section outlines the methodology and indicators chosen for the analysis. In the results section, the climatic suitability of area corresponding to crops, the adaptive capacity and the overall vulnerability of crop production are presented.

Chapter 2 emphasizes the debate of climate-smart agriculture practises. The chapter presents a combination of mixed methodologies to understand the CSA adoption within the target population. In the result section, a description of population characteristics, climate and agriculture context are provided. The next section outlines the CSA prioritization results by farmers and experts, gaps of awareness and adoption of the practises. Cost benefit analysis of CSA practises is presented which later serves for cluster analysis, in order to estimate the adoption probability based on the characteristics of the target population. After that, a brief discussion and conclusion is provided.

Chapter 1: Vulnerability assessment

Summary

We used a geospatial approach to create an index of agricultural vulnerabilities, with three factors to define vulnerability: exposure, sensitivity and adaptive capacity (Fritzsche et al 2014). Together, these factors provide new insights to spatial vulnerability that can support evidence-based decision making towards more resilience to climate change and variability in Vietnam. We chose five crops that are important for food security and national economy. For describing the climate we used the Global Circulation Models for future conditions and WorldClim as the baseline. Then these data sets and crop climate parameters were used in a crop niche model to estimate climatic suitability to grow a crop in a specific area. We also used biophysical indicators to estimate soil erosion and other biophysical impacts and socioeconomic indicators to calculate adaptive capacity. The combination of these factors allowed us to create an index of vulnerability for each crop and to estimate an overall vulnerability score.

The results revealed three different zones with high levels of vulnerability. Zone 1 consists of Son La, Thanh Hoa and Nghe An provinces and is characterized by high erosion potential but with an expected increase in cassava suitability. Zone 2 consists of Kon Tum, Dak lak, Gia Lai, Dak Nong, Lam Dong, Dong Nai and Binh Thuan provinces and is expected to decrease in climatic suitability for rice and Robusta coffee. Zone 3 is the Mekong River Delta region and is the area most threatened by multiple risks, including flooding, drought and sea-level rise with all of these impacting on rice production.

I. The agricultural sector in Vietnam

Vietnam is often considered to be a development success story. Political and economic reforms (Doi Moi) launched in 1986 have transformed the country within a quarter of a century from one of the poorest in the world, with per capita income of USD 100 per year, to lower-middle-income status, with a per capita income of USD 2100 and an estimated GDP growth rate of 6.7% for 2015 (World Bank 2016).

Agriculture is one of the key sectors for the country and by 2000, land for agriculture covered approximately 9.3 million ha, equivalent to 28.2% of the national territory, of which 7.6 million ha were dedicated to growing rice (MONRE 2010). Despite a decrease in the relative importance of agriculture, this sector is still important for the country (see table 1).

Table 1. Gross domestic product (GDP) at current prices by economic sector by Year, Items and Economic sector.

		Structure (%)			
Year	Total (Bill. Dongs)	Agriculture, forestry and fishing	Industry and construction	Service	Products taxes subsidies on production
2009	1,809,149.00	19.17	37.39	43.44	..
2010	2,157,828.00	18.38	32.13	36.94	12.55
2011	2,779,880.00	19.57	32.24	36.73	11.46
2012	3,245,419.00	19.22	33.56	37.27	9.95
2013	3,584,262.00	17.96	33.19	38.74	10.11

Note: 1 USD = 22,500 (Jan 9th 2016).
Value added of economic sectors is calculated at basic prices from 2010.

Source: General Statistics Office of Vietnam (GSO, 2016).

1. Crops selection for the study

(1) For the vulnerability analysis, we prioritized 5 crops from an initial list of 20 based on three indicators (FAOSTAT 2015), which included calorie intake, net production value and harvested area. The results are shown in table 2. Calorie intake (indicator: calorie intake, kcal/capita/day) reveals which crops are sustaining the population and reducing hunger (food supply). Calorie intake is measured by the FAO at the country level and was based on national food balance sheets (Headey and Ecker 2012) and is one of the most commonly used indicators of food security (Rask and Rask 2011, Headey and Ecker 2012, Ruiter et al 2014). A previous report by FAO (2010) focusing on Cambodia used calorie intake as a means of ranking the relative importance of each crop to food security. The approach was also used by Khoury et al (2014) to evaluate the relative importance of crops in global diets. The harvested area of a crop (indicator: total harvested area in hectares) provides information on which crops are most widely grown in Vietnam. Net production value reflects the importance of each crop in economic terms for the economies of the region. This variable captures the important cash crops

that provide vital income for farmers. Through combining calorie intake, harvested area and net production value, it is possible to gain an idea of the overall importance of the respective crop to food security. The results can be seen in table 2.

Table 2. Prioritized crops using calories intake, net production value and harvested area to rank them based on the score of each indicator

Row Labels	Calories (kcal/capita/day)	Score	NPV (US$)	Score2	Harvested Area (ha)	Score3	Total Score
Rice, paddy	1,388	20	10,347,730	20	7,647,602	20	60
Cassava	22	14	972,075	17	531,778	17	48
Nuts, nes (cashew nuts, almond, hazelnut)	19	13	1,050,783	18	326,768	15	46
Maize*	90	19			1,125,078	19	38
Coffee, green**			1,389,394	19	544,033	18	37
Sugar cane	9	9	574,701	15	284,944	14	38
Groundnuts	51	16	213,180	9	227,372	13	38
Bananas	28	15	470,025	14	105,457	7	36
Rubber, natural			933,103	16	474,277	16	32
Soybean	70	17	30,349	0	152,827	11	28

Source: FAOSTAT (2015).

A 5-year average (2009–2013) was used for each of the indicators (calorie, net production value (NPV), harvested area). A 5-year average provides sufficient time to assess trends in the crop.[1] Using the initial list of 20 crops, each of the crops were ranked for the respective indicators, from highest (20) to lowest (0), these values for each of the variables were then aggregated to produce a final total score for the crop. The list of 10 crops with the highest total score was shared with national research institutes to check for their agreement with the prioritization of the crops. Finally 3 crops were selected based on their high total scores: rice, cassava and cashew nuts.* Maize was selected due to its high value for calorie intake and ** coffee because of its high net production value.

1 A 5-year average is often used to capture the recent trends. For instance, The World Food Programme (WFP) selected a 5-year average in order to analyze food insecurity in Somalia (WFP 2012) and proposed that this time period effectively captured the recent situation in Somalia. Furthermore, a study by Salami et al. (2010) on behalf of the African Development Bank, used a 5-year average to look at changes in food prices.

II. Rationale and elements of vulnerability

Vietnam is ranked as one of the ten countries that is most vulnerable to climate change and climate variability in the world (Germanwatch 2016). Progressive climate change will lead to increased temperatures and altering precipitation patterns, resulting in rising sea levels, a higher probability of floods and droughts and more intense tropical cyclones (Coumou and Rahmstorf 2012). Adverse climatic events are affecting the agricultural sector, which along with infrastructure and housing, records the highest economic damage resulting from geophysical hazards in the Asia-Pacific region.

A better spatial understanding of agricultural vulnerabilities, especially among poor, rural households, to climate change and variability is thus fundamental to building more resilient communities and farming systems in Vietnam. This research contributes to a spatial analysis of the three factors that define vulnerability (see figure 1), exposure, sensitivity and adaptive capacity (Fritzsche et al 2014). Together, these features provide new insights on spatial vulnerability that can support evidence-based decision making, which will build resilience to climate change and variability in Vietnam.

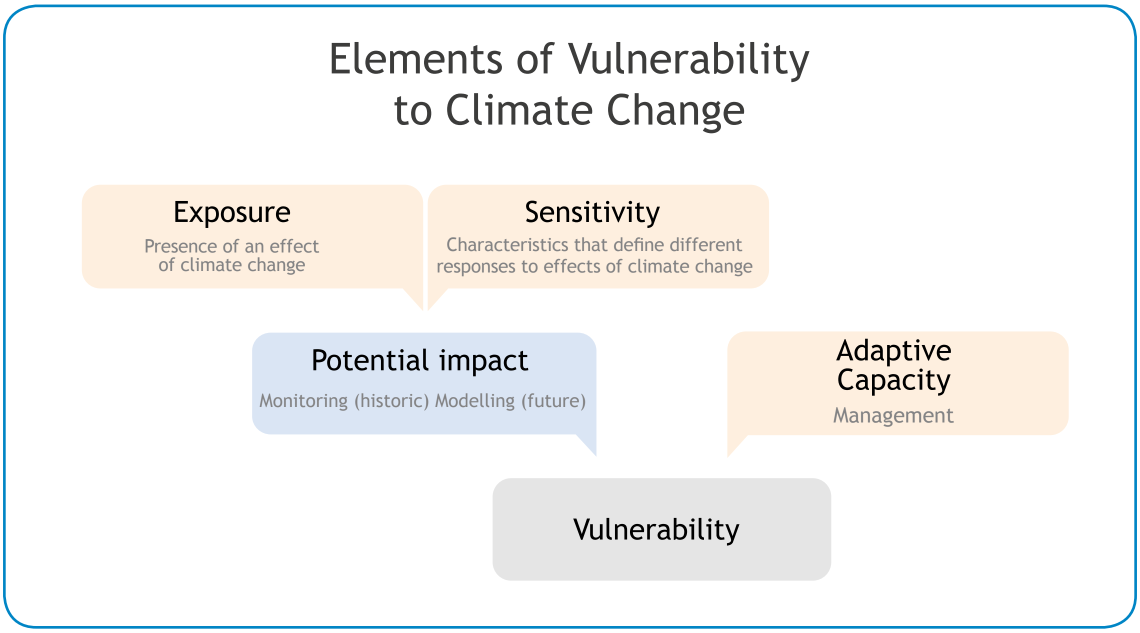


Figure 1. Framework outlining the main components of vulnerability with the necessary components required to assess impacts of climate change on agriculture and rural livelihoods.
Source: Adapted from Marshal et al. (2010).

The distinction between exposure, sensitivity and adaptive capacity is complex and multifaceted. Fritzsche et al (2014) recommends that: "only those factors which are directly determined by climatic factors (such as 'water availability from precipitation') are understood as exposure. The others are 'intermediate impacts.'

However, Smit and Wandel (2006) asserted that exposure and sensitivity were interconnected and were not fixed entities. Thus our definitions of exposure, sensitivity and adaptive capacity are based upon accepted definitions as well as the adopted approach.

We used a combination of components of vulnerability for each of the indicators previously described. The process is shown in figure 2. The steps in the process can be briefly described as follows:

1. Use a global climate model (GCM) for future conditions and WorldClim for current conditions in order to describe changes in temperature and precipitation
2. Use these data sets and crop climactic parameters in crop niche distribution models to estimate climatic suitability to grow a crop in a specific area. Subtract the results for current conditions from future conditions to obtain the change.
3. Use biophysical indicators to estimate soil erosion and other biophysical impacts.
4. Use socioeconomic indicators to calculate the adaptive capacity.
5. Use the change for each crop, related risk from biophysical indicator and adaptive capacity to estimate the vulnerability of each crop.
6. Use the vulnerability for all crops, the harvested area per crop and the harvested area for all crops (xxx) to estimate the overall vulnerability, described in equation 1, for the 5 crops selected in this study.

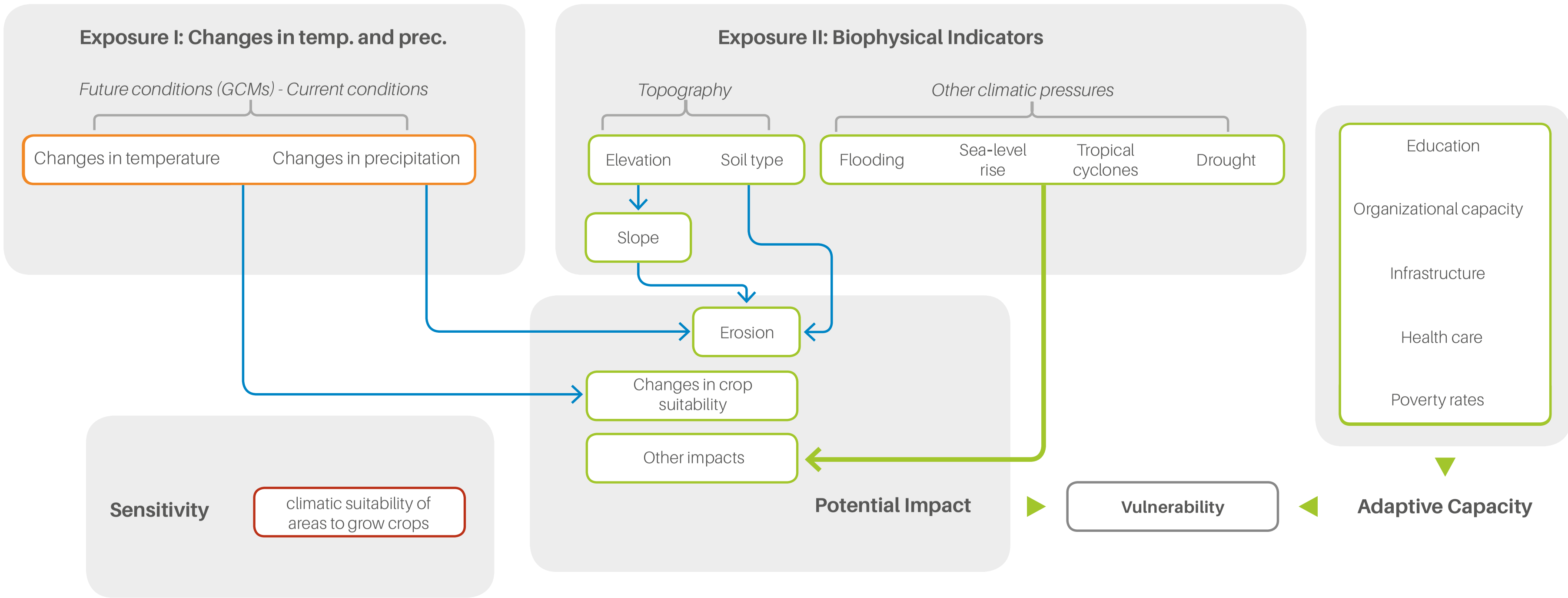


Figure 2. Indicators used to estimate vulnerability.
Source: Own elaboration based on Marshal et al. (2010).

(1)

$$x = Exposure_i + Sensitivity_i + Adaptive\ capacity$$

$$X' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

$$Overall\ vulnerability = \left(\sum_{i=1}^{5} \left(\frac{Harvested\ area_i}{Harvested\ area\ total}\right) * (X'')\right) * (100 - ([N\_crops] * 10))$$

i= Each of the crops

$Harvested\ area_i$ = Harvested area per crop

Harvested area total= Total harvested area for all 5 crops

X'' = Vulnerability index for each crop

N_crops= Number of crops that grow in the district [1–5]

1. Biophysical indicators used to assess exposure and sensitivity

1.1 Exposure

Data to estimate changes in temperature and precipitation.

Current climate: the study is based on the WorldClim (Hijmans et al 2005) database. WorldClim is a high-resolution set of global climatic layers compiled from climate data measured at weather stations from various sources at global, regional, national and local levels, such as the Global Historical Climatology Network (GHCN) and FAO, with records dating from 1950 to 2000. The layers were generated by interpolating monthly averages of climatic data at a spatial resolution of 2.5 minutes of arc (~ 5 km^2 at the equator) using the thin-plate spline algorithm (Hutchinson 1995). The final product provides global climate surfaces for total monthly rainfall and maximum, mean and minimum monthly temperature and is available to download from www.worldclim.org.

Future climate: To anticipate future climate change, we need to project how greenhouse gases (GHGs) will change over the coming decades. The Intergovernmental Panel on Climate Change (IPCC) has developed emission scenarios to represent different alternatives for what may occur in the future. These have been widely used in the analysis of climate change, its impacts and options for mitigation. The Fifth Assessment Report (IPCC 2013) – AR5 – defined four new emission scenarios, called representative concentration pathways (RCPs) developed to be representative of possible future emissions and concentration scenarios published in the existing literature. This is an important development in climate research and provides a potential foundation for further research and assessment, including emissions mitigation and impact analysis (Wayne 2013). Emission scenarios – SRES – used in the AR4 did not consider the effects of possible policy or international agreements aimed to mitigate emissions, representing potential socioeconomic developments unrestricted emissions. In contrast, some of the new RCPs can incorporate the effects of policies to limit climate change for the 21st century. The range of scenarios in RCP is larger compared to the previous reporting scenarios (Knutti and Sedlacek 2012).

The data is formatted in an annual time scale and we calculated three 30-year periods in order to represent a short-, mid- and long-term projection of climate (2040–2069 representing 2050 decadal time period). The future period selected for this study is the 2050s, corresponding to a horizon of medium term. The selected scenario is the RCP 8.5, which is characterized by increasing GHG emissions over time. Although the new RCPs provide a different means of assessing climate change to that of previous scenarios (IPCC Special Report on Emissions Scenarios), the RCP 8.5 (or 'business as usual') represents a situation with a high population growth, relatively low GDP growth and modest rates of technological change and energy efficiency. This leads to significant energy demands and consequent emissions of GHGs. In this scenario, no climate change policies are implemented (Riahi et al 2007). The spatial resolution of GCMs is too coarse to analyse the direct impacts on farmers' production. We therefore downscaled the outputs of each GCM based on the sum of interpolated anomalies to the 2.5 minutes of arc resolution of the monthly climate surfaces of baseline generated before. This method produced a smoothed, interpolated surface of changes in climates forecast derived from the particular GCMs, which was then applied to the baseline climate of WorldClim (Ramirez-Villegas and Jarvis 2010). A list of the used GCMs can be found in annex 1. The changes in precipitation and temperature were estimated by subtracting current from future climate, using the downscaled data sets.

Other climate risks

Flooding

We used an estimate of flood frequency developed by UNEP (2009) in collaboration with the United States Geological Survey (USGS), Earth Resources and Observation Science (EROS) Center and the Dartmouth Flood Observatory 2008. This is based on three sources:

1. GIS modelling using a statistical estimation of peak-flow magnitude and a hydrological model using HydroSHEDS data set and the Manning equation were used to estimate river stage for the calculated discharge value.

2. Observed flood from 1999 to 2007, obtained from the Dartmouth Flood Observatory (DFO).

3. The frequency was set using the frequency from UNEP/GRID-Europe PREVIEW flood data set (UNEP 2009). The data is available at a global scale and a resolution of 0.0083 degrees, or roughly 1 km^2 resolution at the equator. Categorizing the data into weekly intervals enabled the calculation of the number of weeks a year that a particular area was affected by flood. The data was extracted for Vietnam and analysed at the national scale.

Sea-level rise

There is a high degree of uncertainty about the rate of sea-level rise. After consulting the wider literature, we decided to use the Li et al (2009) data set that models a 1 m rise in sea levels. Li et al (2009) is useful as it does not project a sea-level rise for a fixed point in the future, because this brings with it a lot of uncertainty (figure 3). Instead, Li et al (2009) states that if sea levels rise by 1 m, then these areas will be affected. Rather than projecting a sea-level rise for a particular decade, Li et al (2009) provides a fixed 1 m sea-level rise. It is in a GIS format and available at the global scale and with a resolution of 0.0083 degrees or roughly 1 km^2 resolution at the equator. A detailed description of the methodology for deriving the data is available from Li et al (2009). Projecting changes due to the melting of ice caps is particularly complex and as highlighted by Nicholls et al (2011), substantial variation exists between different academic studies (see figure 3 and annex 2). There is further difficulty linking sea-level rise to temperature increase as shown in Figure 3. (Nicholls et al 2011).

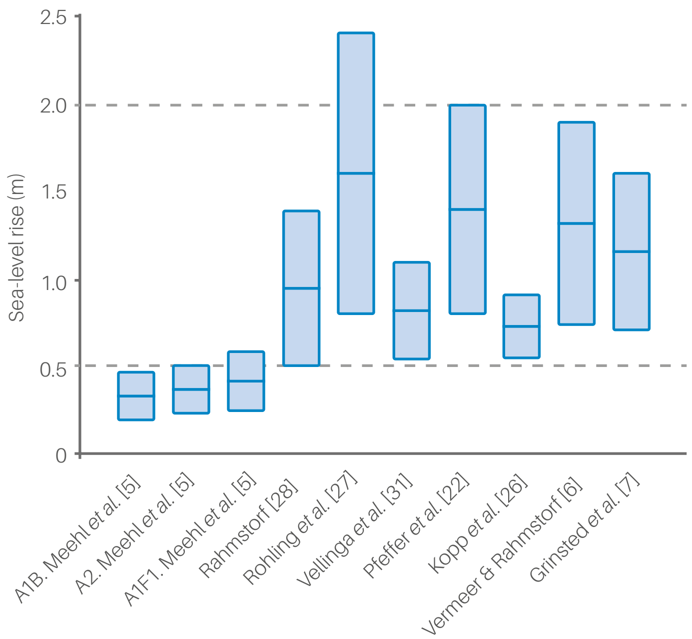


Figure 3. The uncertainty that exists between different studies in projecting sea-level rise. Source: Nicholls et al (2011).

Tropical cyclones

The data for tropical cyclones is available from UNEP (2014) as part of the Global Risk Data Platform, including spatial data, which is downloadable for a number of natural hazards. Spatial data is available for the frequency of events at the global scale and at a resolution of 0.0173 degrees (roughly 2 km^2) at the equator. The data set estimates the tropical cyclone frequency of Saffir-Simpson category 5 (UNEP 2014) for the period 1970–2009.

Drought

A number of data sets are available to assess drought. The complexity of drought and issues in producing global data sets for this variable exist. We used a drought vulnerable area map (ISS 2012) to identify which areas at the national scale are more prone to drought events.

Soil erosion

We estimated the potential erosion using the Universal Soil Loss Equation (USLE), which has been used previously in some areas in Vietnam (Vezina et al 2006, Bien Le Van et al 2014). We calculated the potential erosion for the country using available data from different sources (see table 3) and combined it using GIS. More information and intermediate results can be found in annex 3.

Table 3. Factors and sources for the use of the USLE in Vietnam

Factors	Source
A: annual soil loss rate (ton /ha/yr)	-
R: rainfall factor (MJ.mm/ha.yr)	Hijman et al., 2008; Bien Le Van, 2014
K: soil erodibility factor (ton.ha.h / MJ.ha.mm)	Nguyen, 2009; Ashiagbor et al., 2013; Ranzi et al., 2012; da Silva et al., 2011; GAEZ v3.0 (IIASA/FAO, 2012).
LS: is slope steepness and slope length factor (dimensionless)	DEM - SRTM (Jarvis et al., 2008)
C: cover factor (dimensionless)	C factor from Morgan(2005). Land cover from USGS (Broxton, 2014)
P: conservation practises (dimensionless)	* No information, P = 1

1.2 Exposure

For this study, sensitivity is understood as the change in the climatic suitability of an area to grow a crop. We estimated this change by subtracting the current climatic suitability from the future suitability. For current and future climate data we used the data described in section 1.1 and the Ecocrop model, a crop niche prediction model with the same name as the Food and Agriculture Organization (FAO) Ecocrop database (FAO 2000). The basic model uses environmental ranges (see table 4) as inputs to determine climatic suitability.

Table 4. Parameters used in Ecocrop to identify the climatic suitability of selected crops

	Maize	Cassava	Cashew-nut
	Source	Source	Source
Climatic parameters	Collet et al., 2012, Avat (2013)	Jarvis et al., (2012), Avat (2013)	FAO revised
Gmin	120	240	190
Gmax	120	240	260
Tkmp	0.8	0	0
Tmin	5	15	5
Topmin	22	22	20
Topmax	28.6	32	30
Tmax	30	45	46
Rmin	70	300	400
Ropmin	215	800	1500
Ropmax	650	2200	2000
Rmax	935	2800	3500

Gmin *Growing Season Min (days per year)*

Gmax *Growing Season Max (days per year)*

Tkmp *Killing Temperature (°C)*

Tmin *Temperature Min (°C)*

Topmin *Temperature Optimum Min (°C)*

Topmax *Temperature Optimum Max (°C)*

Tmax *Temperature Max (°C)*

Rmin *Rainfall Min (mm) for the growing season*

Ropmin *Rainfall Optimum Min (mm) for the growing season*

Ropmax *Rainfall Optimum Max (mm) for the growing season*

Rmax *Rainfall Max (mm) for the growing season*

For Robusta coffee and rice we used a different method (MaxEnt) to estimate the climatic suitability. Maximum entropy (MaxEnt) is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent the incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real valued variables, known as features and the constraints are that the expected value of each feature should match its empirical average -"average value for a set of sample points taken from the target distribution"(Phillips et al 2006). Similar to logistic regression, MAXENT weighs each environmental variable by a constant. Regarding the data used as evidence points, for rice we used a map from IRRI (see annex 7) and for coffee from Cafecontrol (see annex 8). Using GIS, both maps were converted to GRID format and then into points, using these points for training the model along with the bioclimatic variables.

Within the WorldClim database (Hijmans et al 2005), there are bioclimatic variables derived from monthly temperature and rainfall values to generate more biologically meaningful variables, which are often used in ecological niche modelling (e.g. BIOCLIM, GARP). The bioclimatic variables represent annual trends (e.g. mean annual temperature, annual precipitation), seasonality (e.g. annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month and precipitation of the wettest and driest quarters).[2]

The derived bioclimatic variables are:

Bio1 = Annual mean temperature
Bio2 = Mean diurnal range (Mean of monthly (max temp - min temp))
Bio3 = Isothermality (Bio2/Bio7) (* 100)
Bio4 = Temperature seasonality (standard deviation *100)
Bio5 = Maximum temperature of warmest month
Bio6 = Minimum temperature of coldest month
Bio7 = Temperature annual range (Bio5 – Bi06)
Bio8 = Mean temperature of wettest quarter
Bio9 = Mean temperature of driest quarter
Bio10 = Mean temperature of warmest quarter
Bio11 = Mean temperature of coldest quarter
Bio12 = Annual precipitation
Bio13 = Precipitation of wettest month
Bio14 = Precipitation of driest month
Bio15 = Precipitation seasonality (coefficient of variation)

2 A quarter is a period of three months (1/4 of the year).

Bio16 = Precipitation of wettest quarter

Bio17 = Precipitation of driest quarter

Bio18 = Precipitation of warmest quarter

Bio19 = Precipitation of coldest quarter

The following framework (see figure 4) describes how we modelled and assessed the change in climatic suitability at district level and for each crop. We used Monfreda et al (2008) data for the probability of presence of each crop within Vietnam's boundaries. We created 1000 weighted points that were used to assess a threshold of suitability of the crop based on the current suitability. From this threshold of suitability, we reclassified the outputs of Ecocrop into two classes: suitable or not and we aggregated the values at the district level. We used harvested areas data (from the General Statistics Office of Vietnam) at a provincial level, except for cassava, to mask out the areas for current and future suitability results where the province had very low harvesting areas. Finally, the difference between future and current suitability at the district level was computed in order to obtain the suitability change for the particular crop.points which were used to assess a threshold of suitability of the crop based on the current suitability. From this threshold of suitability, we reclassified the outputs of Ecocrop into two classes: suitable or not, and aggregated the values at the district level. We used harvested areas data (from the general statistics office of Vietnam) at a provincial level, except for cassava, to mask out the areas for the current and future suitability results where the province had very low harvesting areas. Finally, the difference between future and current suitability at the district level was computed in order to obtain suitability change for the particular crop.

Based on the results from the models for future changes in the climatic suitability we used an index to group and include the positive and negative impacts (see table 5) on final vulnerability.

Table 5. Description, changes in percentage and the sensitivity index used as one of the factors to estimate vulnerability

	Changes (%)	Sensitivity Index
Negative	-50 - -100	1
	-25 - -49	0.5
	-5 - -24	0.25
No change - no crop presence (5 selected crops)	- 5 - +5	0
Positive	5 - 24	-0.25
	26 - 49	-0.5
	50 - 100	-1

In order to assess the potential impacts of current and future climatic related risks for each crop, we used a combination of the changes in climatic suitability to grow crops (sensitivity) and biophysical indicators.

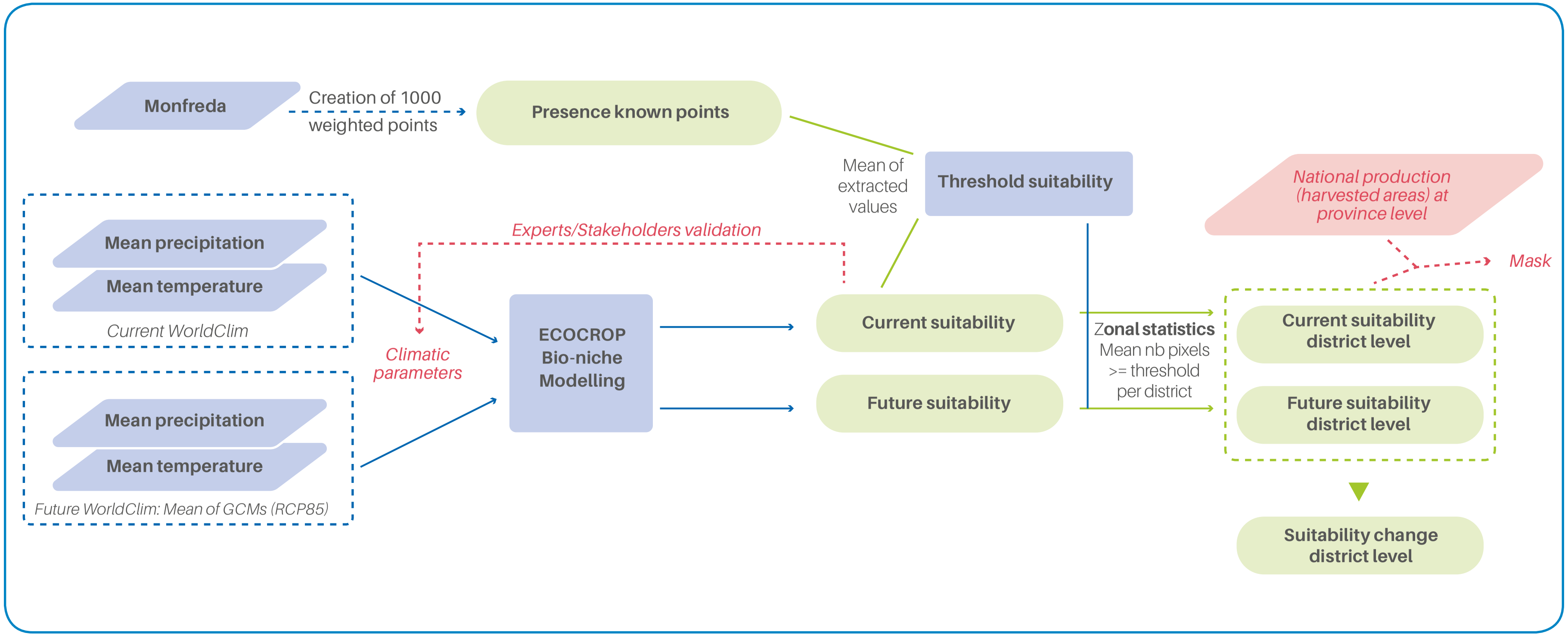


Figure 4. Methodology for estimating the future change in climatic suitability for growing crop in a specific area

2 Socioeconomic indicators to assess adaptive capacity

2.1 Organizational capacity

To estimate this indicator, we used the quotient of the number of agricultural cooperatives over the number of total farms at a provincial level, using official data from the General Statistics Office of Vietnam (GSO 2005a).

2.2. Education

We used the "percentage of graduates compared with total upper secondary candidates" (GSO 2011) which is the proportion of graduating high school students compared to the number of students completing each grade of a defined school year.

2.3 Accessibility

Accessibility was derived from a combination of several data sets. Travel time was computed in hours to urban areas of >50 000 people. Input maps were divided into target locations (populated places) and friction surfaces (road networks, railway networks, navigable rivers, major water bodies, shipping lanes, national borders, land cover, urban areas, elevation, slope) with a resolution of 30 seconds of arc (Nelson 2008).

2.4 Gini coefficient

Income discrepancy and poverty differentiation are recognized through the Gini coefficient. The Gini coefficient varies between 0 and 1. A Gini coefficient of 0 expresses perfect equality, where all values are the same (e.g. where everyone has the same income). A Gini coefficient of 1 expresses maximal inequality (GSO 2005b). Data was produced at the district level for the National Economics University from Hanoi, Vietnam in 2009 and the results at a provincial level were used by Lanjouw et al (2013). The values were inverted to show high values as equality and low as inequality in order to match it with other indicators.

2.5 Health

Health indicators are at a provincial level. These are in percentages for underweight, stunting and wasting of total population. They were averaged and then inverted in order to present high values for those with less underweight, stunting and wasting problems.
$[(Health/100)-1]*-1$.

2.6 Adaptive capacity classification

With all indicators in the same range of values from 0 to 1, they were averaged. Then, in the results, 0 meant no organizational capacity, no education, a long time to travel to populated places, inequality and high problems of underweight, stunting and wasting. Conversely, values close to 1 meant the opposite, as shown in figure 5.

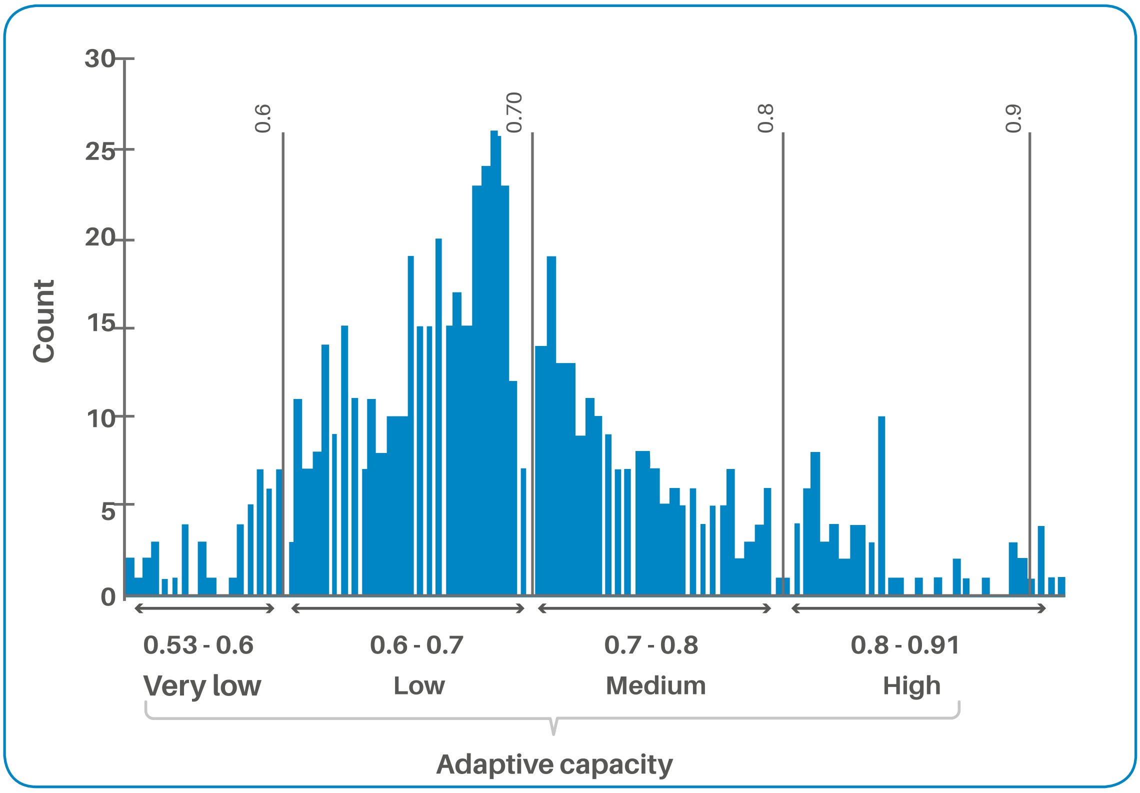


Figure 5. Distribution and classification of results for adaptive capacity.
Source: Own elaboration.

In order to simplify the analysis and the discussion of this result, four classes were created and represented graphically: 0–53 as very low, 0.6–0.7 as low, 0.7–0.8 as medium and 0.8–0.91 as high adaptive capacity.

III. Results

Climatic suitability of crop-growing areas

The maps shown in figure 6 represent the current suitability. The grey colour is the mask from the provincial data for areas that have a low yield for each crop and the red colour shows areas with current low suitability.

In the case of maps for suitability changes, shown at the right in the graph, crops with increasing suitability are shown in green and those losing suitability are shown in red. Beige areas are expected to remain close to current conditions.

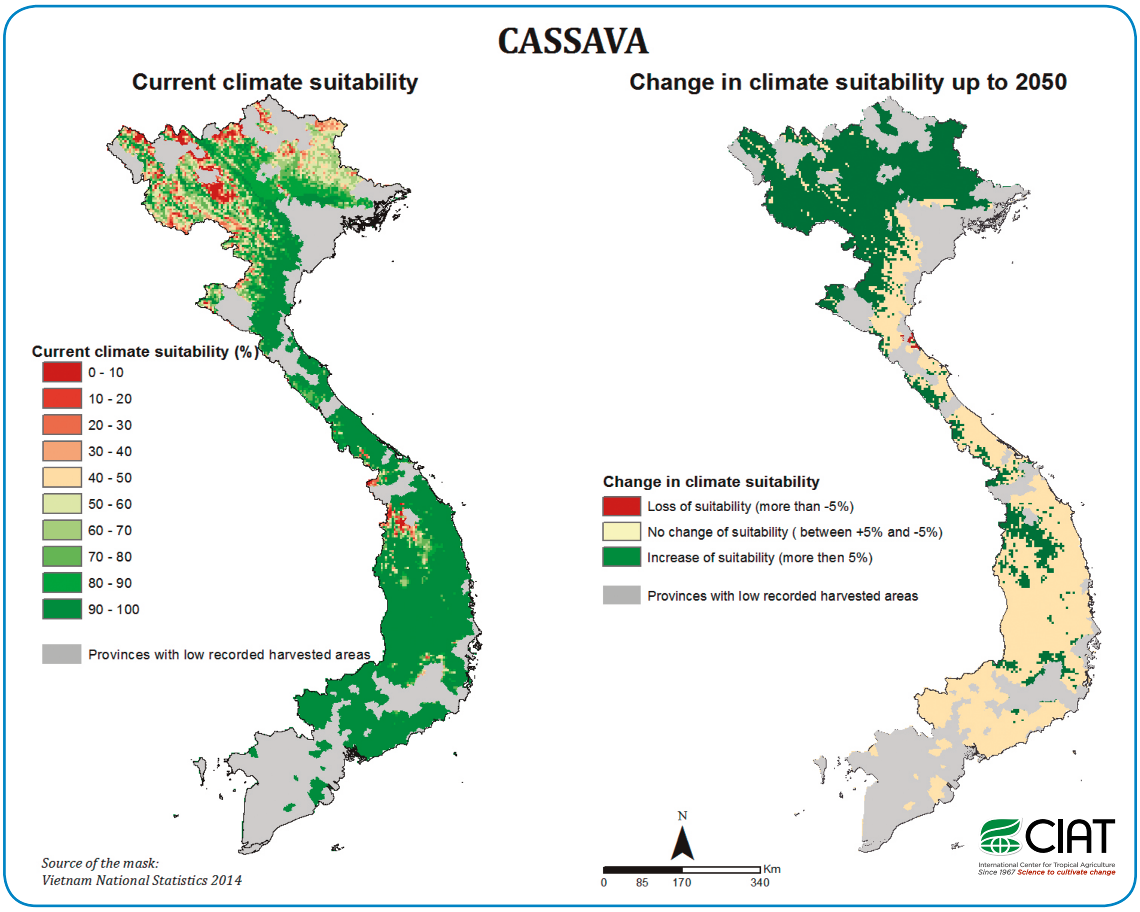
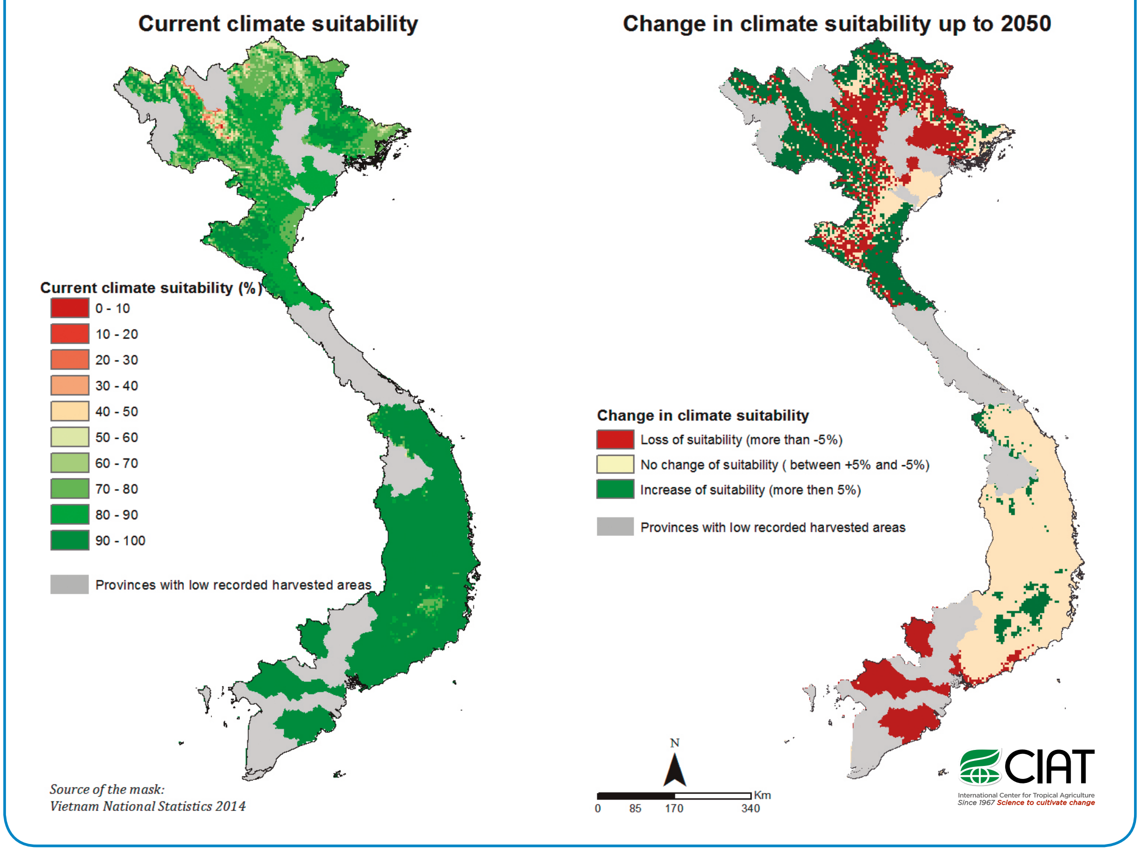


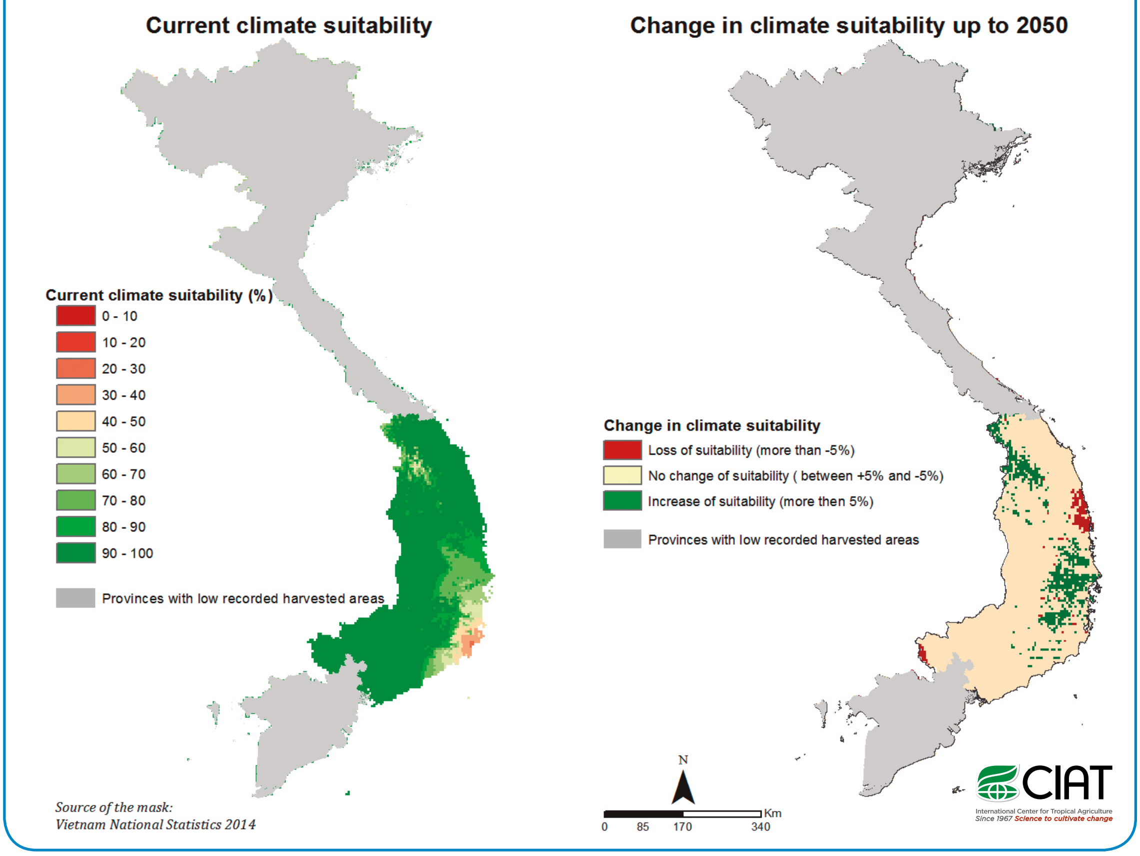
Figure 6. Results for each crop at current (left) and changes by 2050's conditions (right), considering the impact of temperature and precipitation only.
Source: Own elaboration.

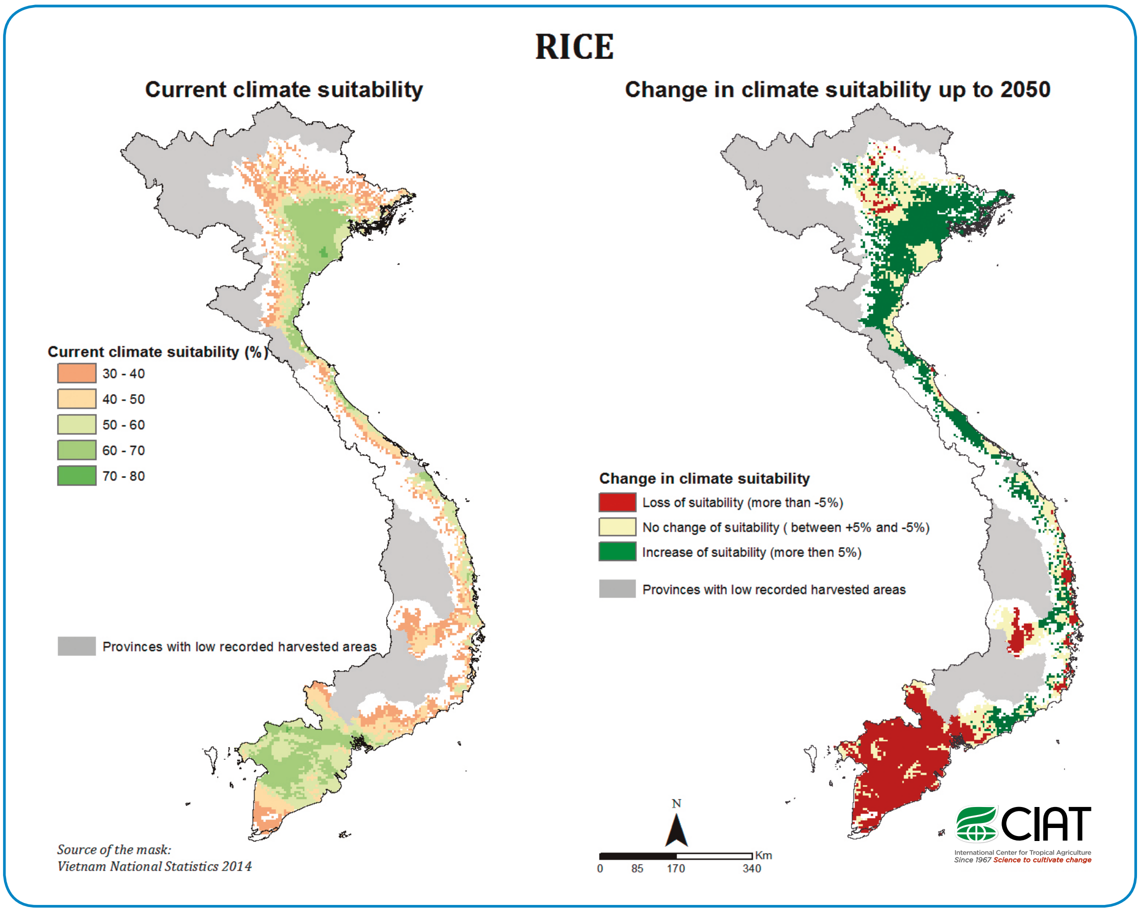
*Note: This figure is not intended to be an exhaustive representation of the territorial space of Vietnam. (continues)

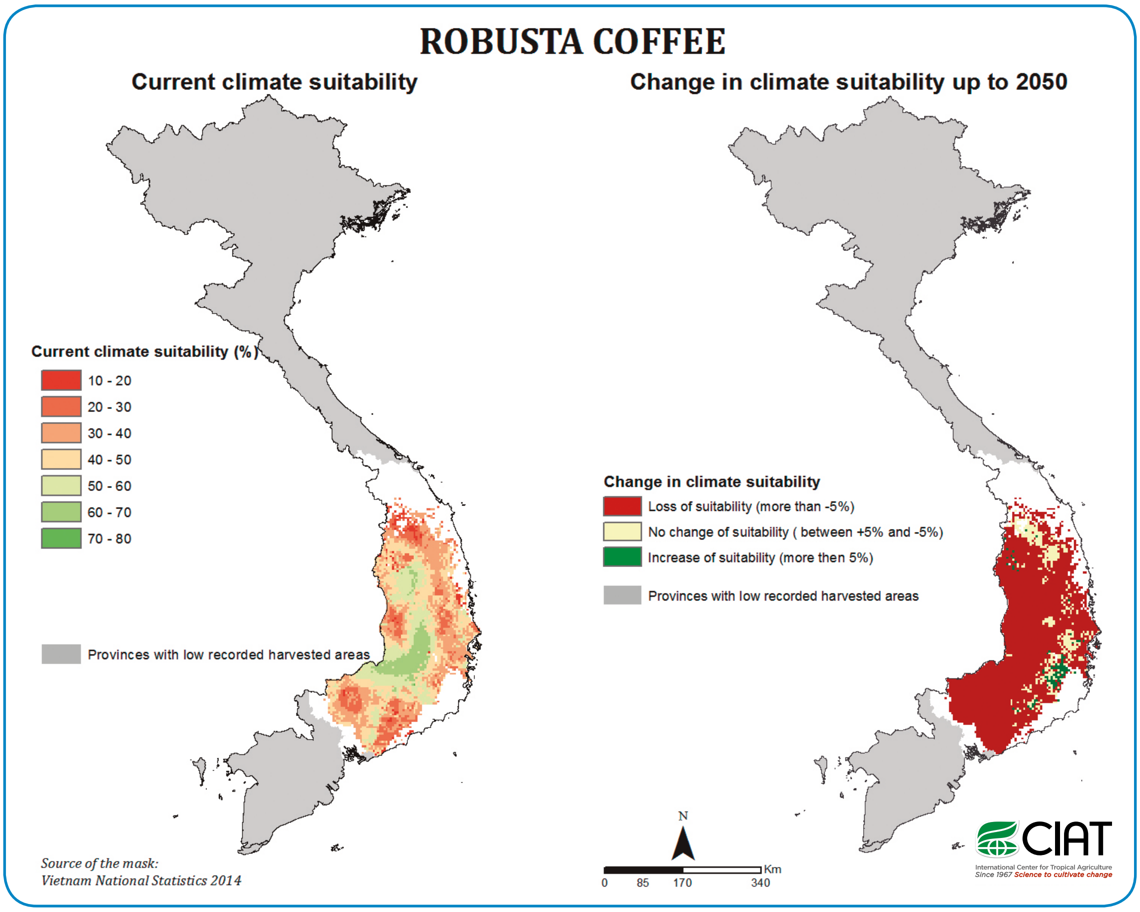
MAIZE



CASHEW




RICE
Current climate suitability
Change in climate suitability up to 2050
Current climate suitability (%)
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
Provinces with low recorded harvested areas
Source of the mask:
Vietnam National Statistics 2014
Change in climate suitability
Loss of suitability (more than -5%)
No change of suitability (between +5% and -5%)
Increase of suitability (more then 5%)
Provinces with low recorded harvested areas
N
0 85 170 340 Km
CIAT
International Center for Tropical Agriculture
Since 1967 Science to cultivate change


ROBUSTA COFFEE
Current climate suitability
Change in climate suitability up to 2050
Current climate suitability (%)
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
Provinces with low recorded harvested areas
Source of the mask:
Vietnam National Statistics 2014
Change in climate suitability
Loss of suitability (more than -5%)
No change of suitability (between +5% and -5%)
Increase of suitability (more then 5%)
Provinces with low recorded harvested areas
N
0 85 170 340 Km
CIAT
International Center for Tropical Agriculture
Since 1967 Science to cultivate change

For cassava, maize and cashew, based on changes in temperature and precipitation (annex 4) we estimated the change in climatic suitability of each crop. Those results show that there are no large changes in suitability for these 3 crops as a consequence of temperature and precipitation increases. An exception to this is maize in the Mekong River Delta and the Northeast region, where this crop might lose more than 5% of suitability. According to the Ecocrop model (table 4), when analysing only the impact of climate change for 2050, more areas are increasing rather than loosing suitability (see figure 6).

According to the MaxEnt model, areas for growing rice will decrease their suitability in the Mekong River Delta and increase in the Red River and in Northeast regions. These changes in suitability are directly related to increases in the mean temperature of the warmest quarter and the maximum temperature of the warmest month.

For Robusta coffee, the results from MaxEnt show that there might be a decrease in suitability in all regions that grow this crop, except in the northeast part of Lam Dong province. Increases in temperature seasonality and in the mean temperature in the wettest quarter account for about 75% of the change in suitability.

Adaptive capacity

Figure 7 shows 49 districts with very low, 372 with low, 202 with medium and 70 with high values for adaptive capacity.

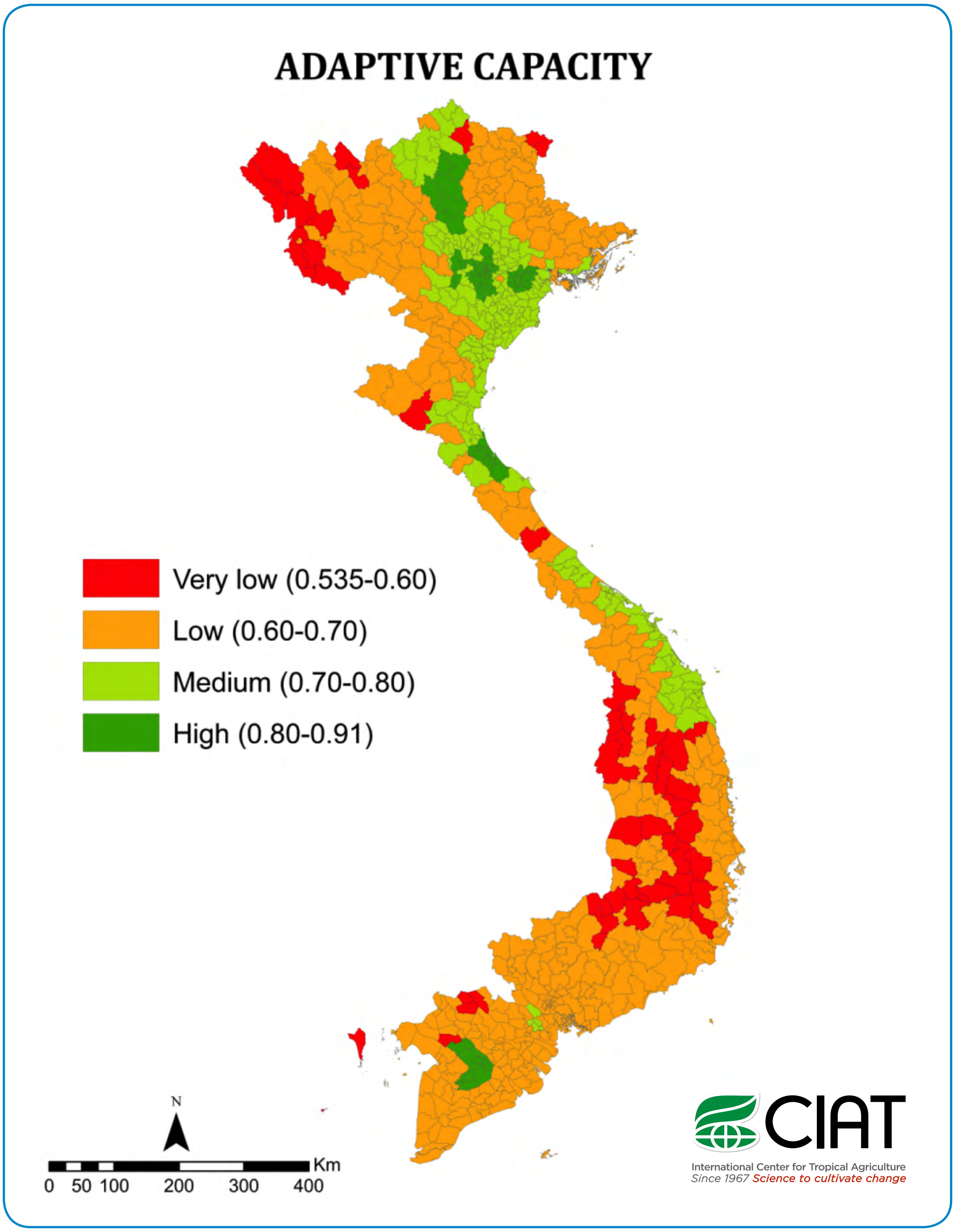
The values for very low and low adaptive capacity were influenced mainly by accessibility and organizational capacity (see annex 6). Accessibility values ranged from 0–0.99 with a mean of 0.78 and a standard deviation (STD) of 0.17, but for districts in the very low class, the mean was 0.44 with a STD of 0.15. For organizational capacity, the range for all districts was 0–1 with a mean of 0.2 and a STD of 0.24. For those with very low adaptive capacity the values ranged from 0–0.35 with a mean of 0.06 and a STD of 0.08. Figure 7 shows that more remote districts have less organizational capacity (cooperatives) and should be considered as less prepared to cope with climatic impacts.

The bottom five districts for adaptive capacity are: Krong Nang, Lak, Tan Hong, Muong Cha and Krong Bong with a score of less than 0.545.

Most of the districts with very low adaptive capacity are concentrated into two zones: the Northwestern region bordering Lao PDR and the Central Highlands.

Vulnerability by crop

Using the results from biophysical indicators to estimate soil erosion and other impacts (see annex 5) and the results from adaptive capacity combined with the results for changes in suitability, we can estimate the vulnerability for each crop. This provides us with five different



*Note: This figure is not intended to be an exhaustive representation of the territorial space of Vietnam.

Figure 7. Adaptive capacity based on selected socio-economic indicators.
Source: Own elaboration.

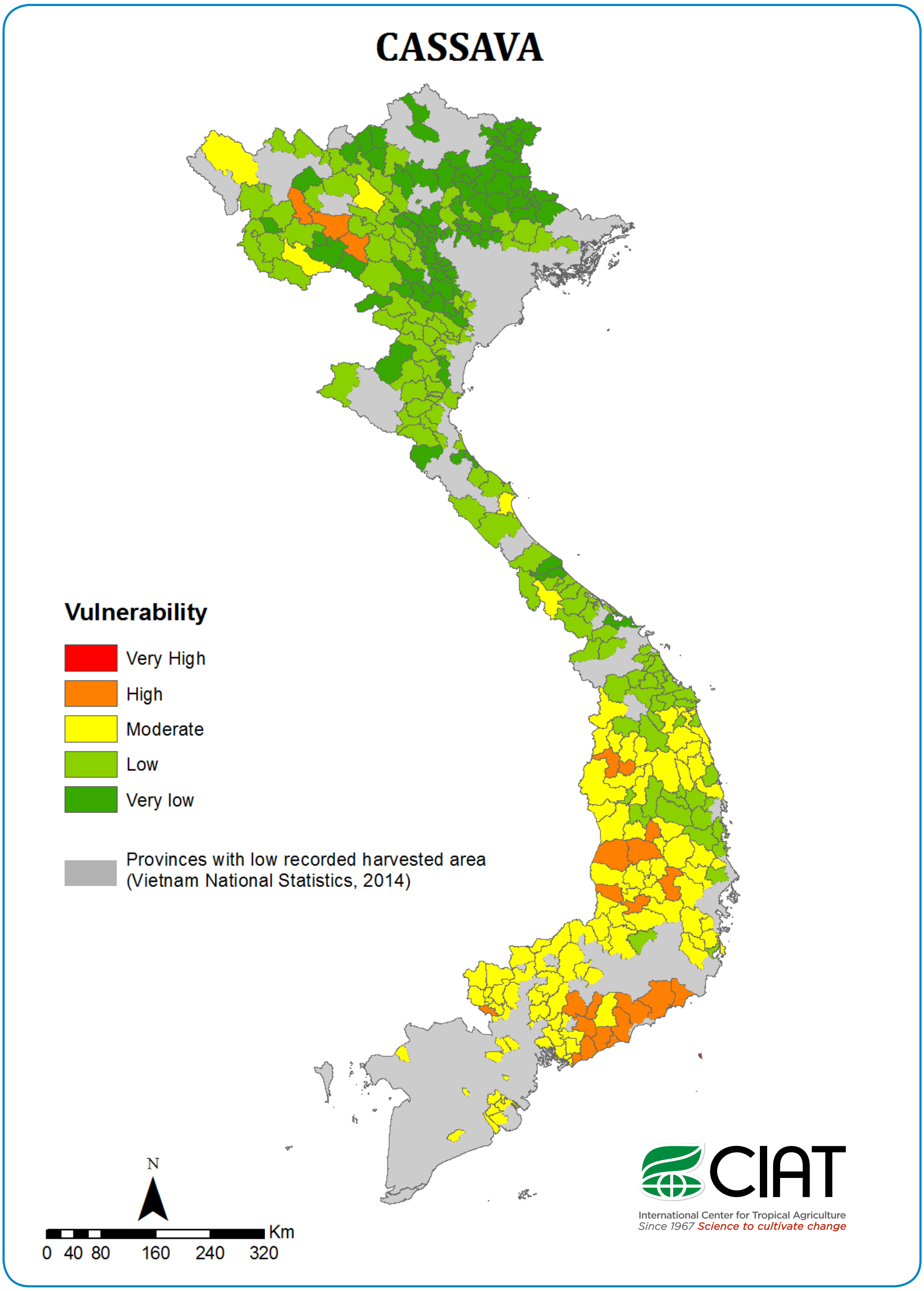
levels of vulnerability when considering the impacts of climate change along with possible impacts from: drought, sea-level rise, soil erosion, flooding and tropical cyclones (see figure 8).

In the case of maize, temperature increase in the Northeast region with consequent loss of suitability, low adaptive capacity and related risks such as tropical cyclones, soil erosion and flooding, might lead to high vulnerability, mainly in Luc Ngan, Hoanh Bo and Cam Pha districts. Meanwhile, most of districts in An Giang are very highly vulnerable due to drought, floods and low adaptive capacity.

In Sa Thay, very low adaptive capacity combined with high soil erosion risk and drought makes the classification for this district as highly vulnerable for the production of Robusta coffee and cassava. Bac Yen is also classified as vulnerable for production of both crops because of its high potential for soil erosion and low adaptive capacity.

For Binh Thuan, the model for climatic suitability shows no change for 2050, but this province has a very high vulnerability for production of cassava as a consequence of low adaptive capacity and high drought risk.

The Mekong River Delta region is threatened by sea-level rise and is prone to drought and flooding, threatening rice production.



*Note: This figure is not intended to be an exhaustive representation of the territorial space of Vietnam.

Figure 8. Vulnerability for each crop
Source: Own elaboration.

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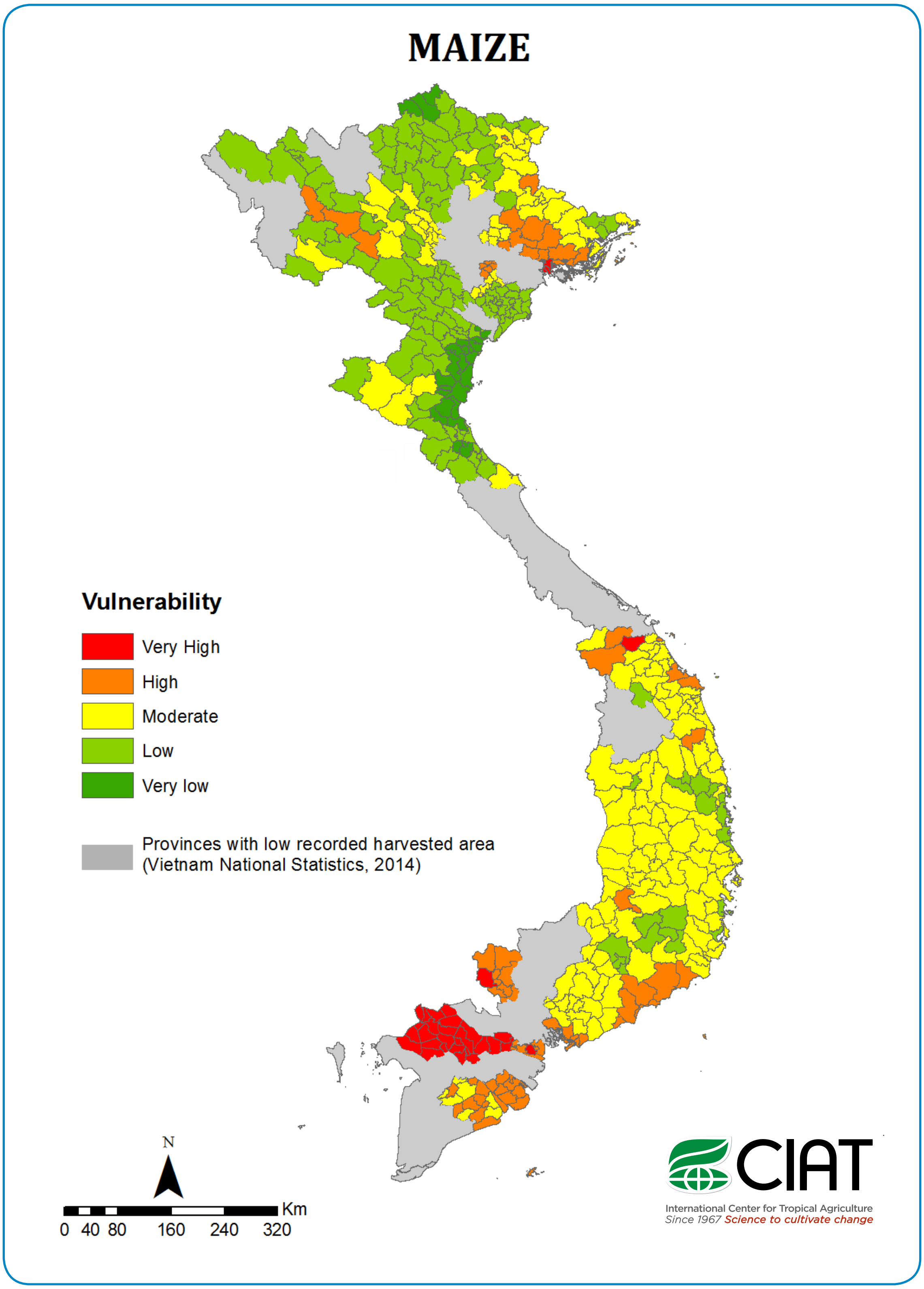

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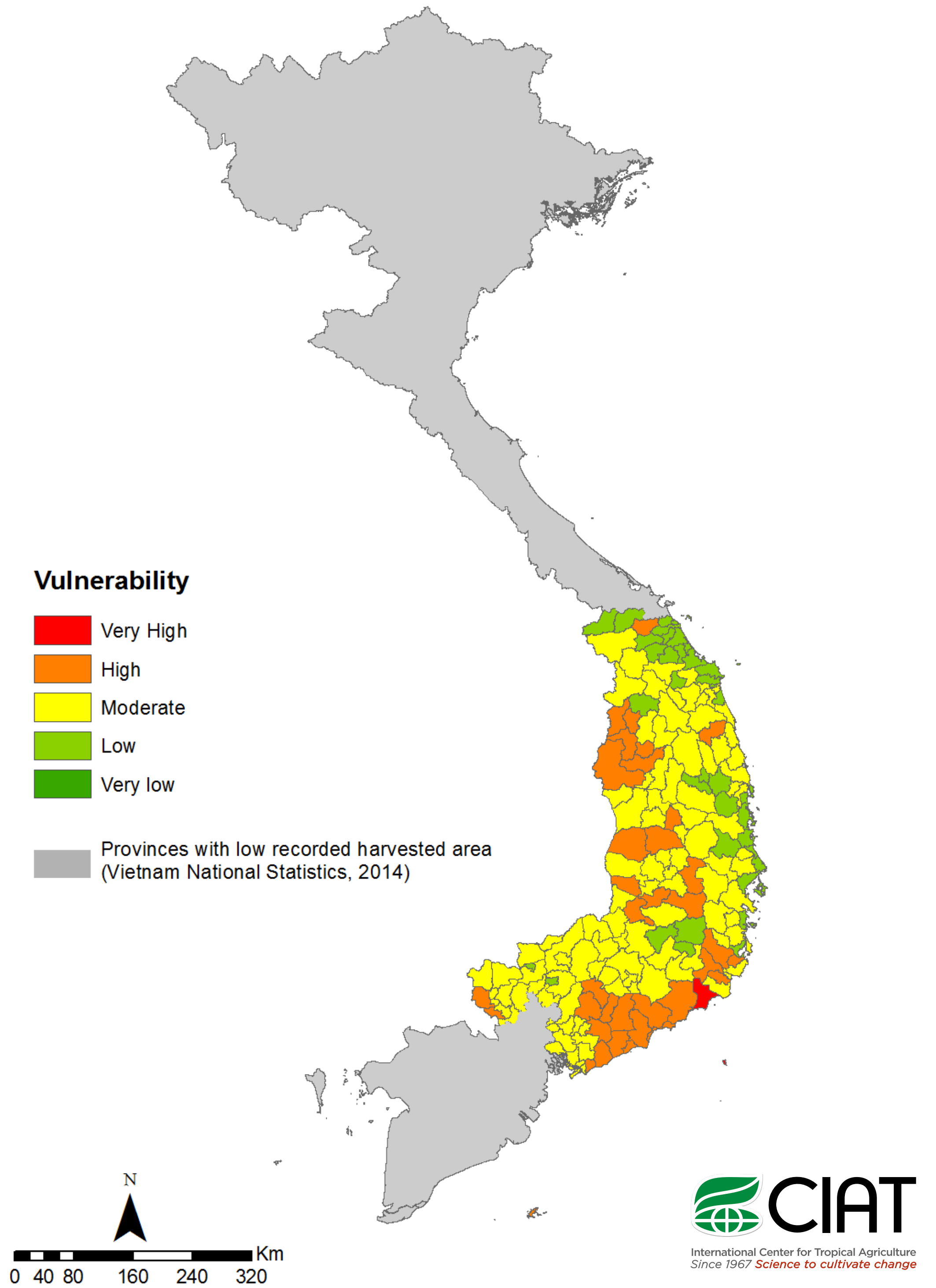
CASHEW



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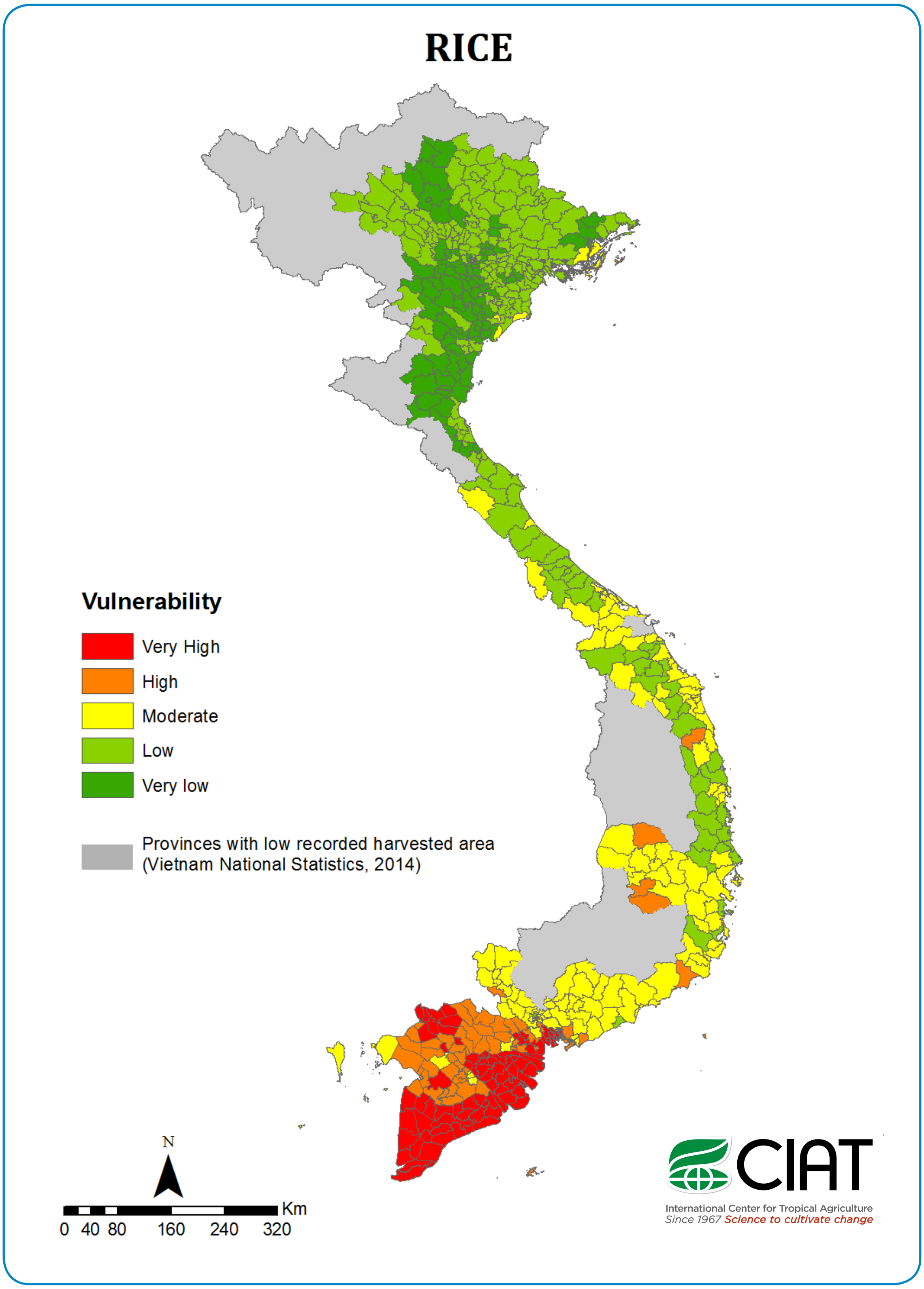

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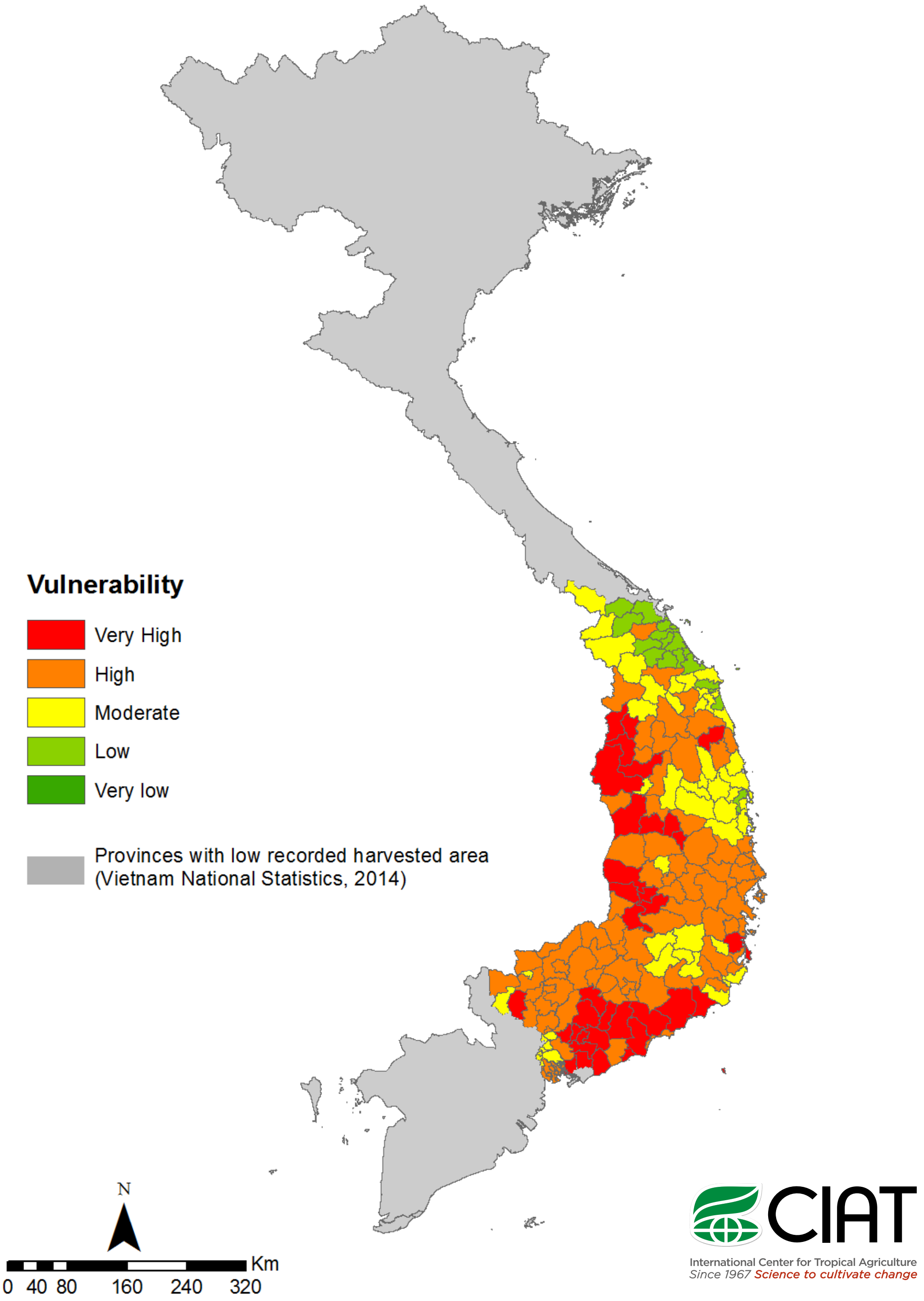
ROBUSTA COFFEE



The districts of Bac Binh and Tuy Phong are mainly affected by soil erosion and drought, which combined with low adaptive capacity, leads to high vulnerability for the production of cashew.

Overall vulnerability scores for crop production

All the previous analyses for crop vulnerability were combined and weighted using the areas for each crop over the total agricultural area. The result is shown in figure 9.

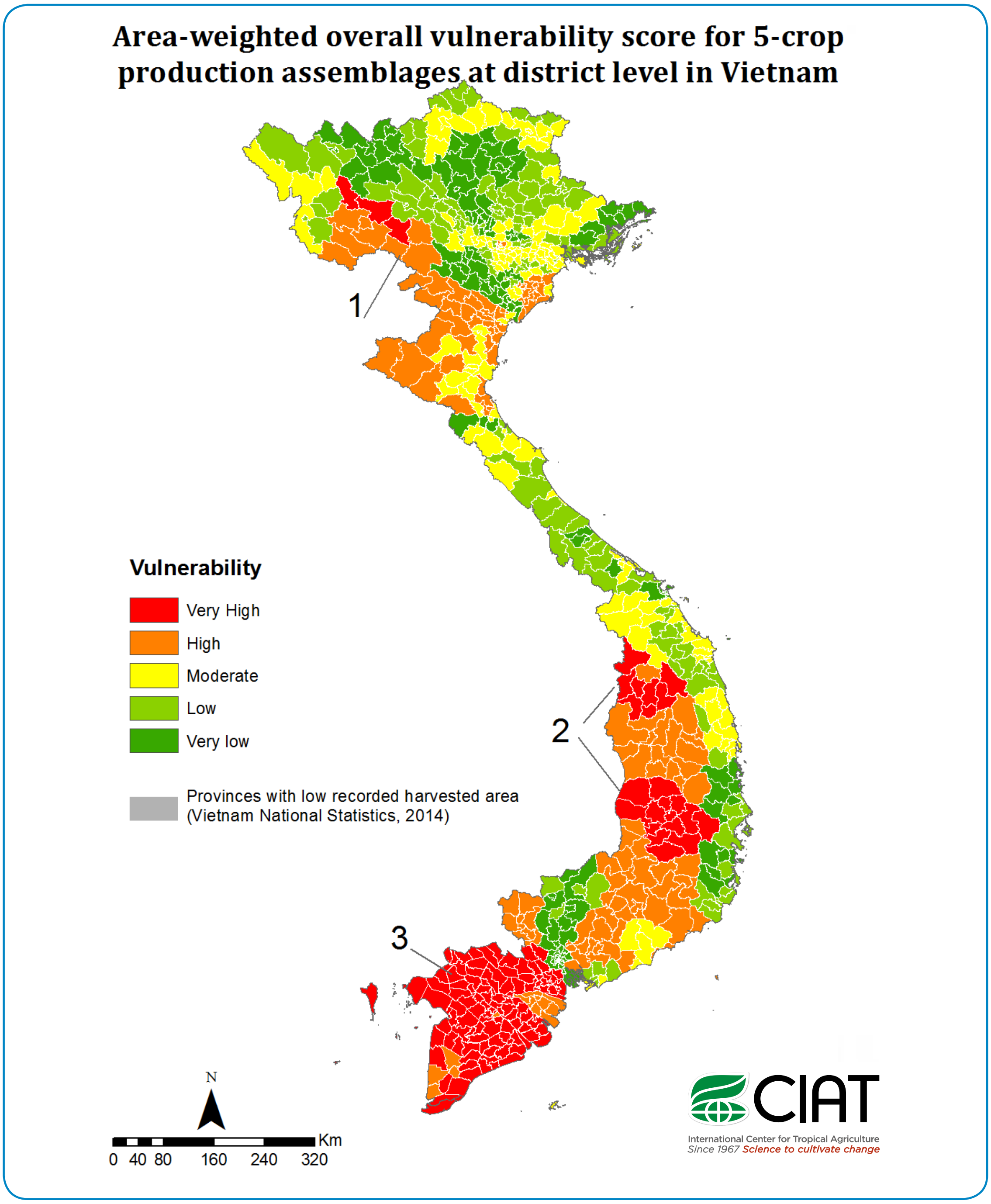


Figure 9. Overall vulnerability score for the 5 selected crops
Source: Own elaboration.

*Note: This figure is not intended to be an exhaustive representation of the territorial space of Vietnam.

The result shows 3 different zones with high levels of vulnerability. Zone 1 consists of Son La, Thanh Hoa and Nghe An provinces. The high index of vulnerability in this zone is influenced by a high potential for soil erosion, a low adaptive capacity and loss of climatic suitability for maize. Although, according to niche distribution models, the climatic suitability for cassava might increase.

Zone 2 consists of Kon Tum, Dak Lak, Gia Lai, Dac Nong, Lam Dong, Dong Nai and Binh Thuan provinces. The two first provinces have very high vulnerability due to probable loss in climatic suitability to grow rice and Robusta coffee by 2050. This zone is also prone to drought and the population from this zone is in the range of very low adaptive capacity.

Zone 3 consists of the Mekong River Delta region. The results show very high vulnerability mainly caused by the loss of climatic suitability for growing rice, low adaptive capacity, flooding, sea-level rise and droughts.

Limitations of the study

A major constraint has been the lack of data at district level for data, such as the number of agricultural cooperatives over the number of total farms, percentage of graduates compared with total candidates at upper secondary schools, number of people who are underweight, and levels of stunting and wasting. The same problem occurs with harvested area data, which is only available at provincial level. Hence the use of a mask based on this information may lead to errors, such as not including some districts as high producers for the selected crops.

Some important crops such as pepper and rubber were not included in the study because of the absence of climatic parameters for optimal growing areas. Despite this, the methodology is open to include new crops or new socioeconomic data for adaptive capacity, so vulnerability for those crops or system could be estimated.

This study includes current natural risks and climate change. It doesn't include climate variability. The models Ecocrop and MaxEnt both used climatic variables only and did not include soil variables.

This study took into account only of the five major biophysical exposure variables and did not include salinity intrusion, which is a major threat in Vietnam, particularly in the Mekong Delta region.

IV. Conclusions

1. According to socioeconomic indicators used in this study, which are based on the availability of data, most of the Vietnam's districts demonstrate low adaptive capacity. Districts with very low adaptive capacity are located in the Central Highlands, Northwest and Northeast regions. More analyses, as well as more investments are needed in the key sectors of public health, accessibility and infrastructure and organizational capacity in order to increase adaptive capacity.
2. Zone 1: In Son La, Thanh Hoa and Nghe An provinces, two main concerns should be addressed. Soil erosion and cassava are both currently present in these areas and both are expected to increase in the future. This highlights the need for investment in cassava value chain improvement and promotion of soil conservation techniques including stimulation of rapid early crop growth and canopy closure to protect the soil, improve water infiltration into the soil and reduce the length or steepness of the slope (CIAT 2014). These areas might lose suitability for maize due to a temperature increase (+2°C by 2050), which could lead to use of maize varieties adapted to high temperatures.
3. Zone 2: The Central Highlands and South Central Coast regions are within this zone. The two most important crops in this zone are Robusta coffee and cashew, both of which are considered as high-value commodities for export. According to the results, cashew will remain in the same climatic suitability into the 2050s but the areas for Robusta coffee and rice may decrease. Robusta coffee could be affected by higher climate variability. Drought incidence is a main risk for this zone. Key investments should focus on agroclimatic information services and water management.
4. Zone 3: In Zone 3, in the Mekong Delta, rice is threatened by climate change, specifically by temperature increases. This zone is also the most threatened by natural hazards including drought, flooding and a sea-level rise. In this zone, investment should focus on agroclimatic information services for better-informed decision and multi-risk planning, infrastructure to cope with natural risks and research on practises and varieties for rice adaptation for high temperatures and salinity intrusion.

Chapter 2: Challenges and opportunities for climate-smart agricultural practises adoption. Case study in Tra Vinh and Ben Tre provinces, Vietnam

I. Introduction

The densely populated MRD region is one of the major crop-producing areas in Vietnam where rural communities are particularly vulnerable to climate change due to their dependence on rainfed agriculture. The area is facing the threats of climate change, with increased weather variability and extreme weather events expected to reduce agricultural yields, lessen the availability of fresh water and further degrade biodiversity and ecosystem services. Rising sea levels are predicted to affect about 20–25% of the low-lying delta by the end of this century (Nicholls et al 2007). Human activity including intensive farming practises such as overfertilization, excessive application of pesticide application and overtilling, has led to land degradation, increased pest pressure and soil erosion, all of which is steadily reducing land productivity and yield.

Under the umbrella of ASAP, the Adaptation in the Mekong Delta (AMD) project seeks to develop sustainable livelihoods for the rural poor who face the challenges of a changing climate and strives to enhance the adaptive capacity of communities, institutions and smallholder farmers in the MRD of Vietnam. One of the objectives of the project is to provide financial and technical support for the adoption of agricultural practises and technologies that address adaptation, mitigation and food security in the targeted area. This strategy is defined as 'climate-smart agriculture' (CSA) practises.

The adoption of CSA practises is constrained by various factors: policy and institutions, funding, research, training and technical capacity and socioeconomic aspects (Harvey et al 2014). These factors vary greatly with spatial and temporal conditions; thus it is necessary to conduct more participatory, action-oriented research with farmers to ensure better planning of CSA strategies in different agroecological and socioeconomic contexts (FAO 2013, Harvey et al 2014, Steenwerth et al 2014).

The general aim of the chapter was to understand farmers' preferences for CSA practises and identifying the opportunities and challenges of CSA adoption in the Mekong Delta region. The adoption of CSA practises is vital in increasing resilience and sustaining the livelihoods of affected farmers. But which CSA should be adopted by who? What are the costs of the selected CSA practises? Answering these questions is an essential step in designing an effective CSA strategy.

The specific objectives include:

- understanding contextual agricultural production system and climate problems;
- identifying bottom-up or climate adaptation practises;
- assessing the costs and benefits of selected CSA practises;
- assessing the challenges and opportunities of adoption of CSA practises for different groups of the population.

II. Methodology

1. Overall methodology

In the study, sequential, exploratory mixed methods (Creswell et al 2003) were used to collect both qualitative and quantitative data. Qualitative data was gathered through a series of transect walks and participatory farmer and expert workshops, while quantitative data was collected through household surveys. The qualitative data from participatory farmer and expert workshops provided valuable insights on contextual community-level information, including local agricultural production conditions, climate variability and existing or potential solutions/ practises for climate change. This data later served as a basis for designing a questionnaire for a household survey which was used to re-assess contextual information at household level and to further measure the magnitude, adoption rate and knowledge of CSA practises of different household typologies. Given that information greatly varies across scales, the implementation of participatory workshops and household surveys helped to fill information gaps, comparing findings across scales and to interpret findings in both theoretical and empirical ways (figure 10).

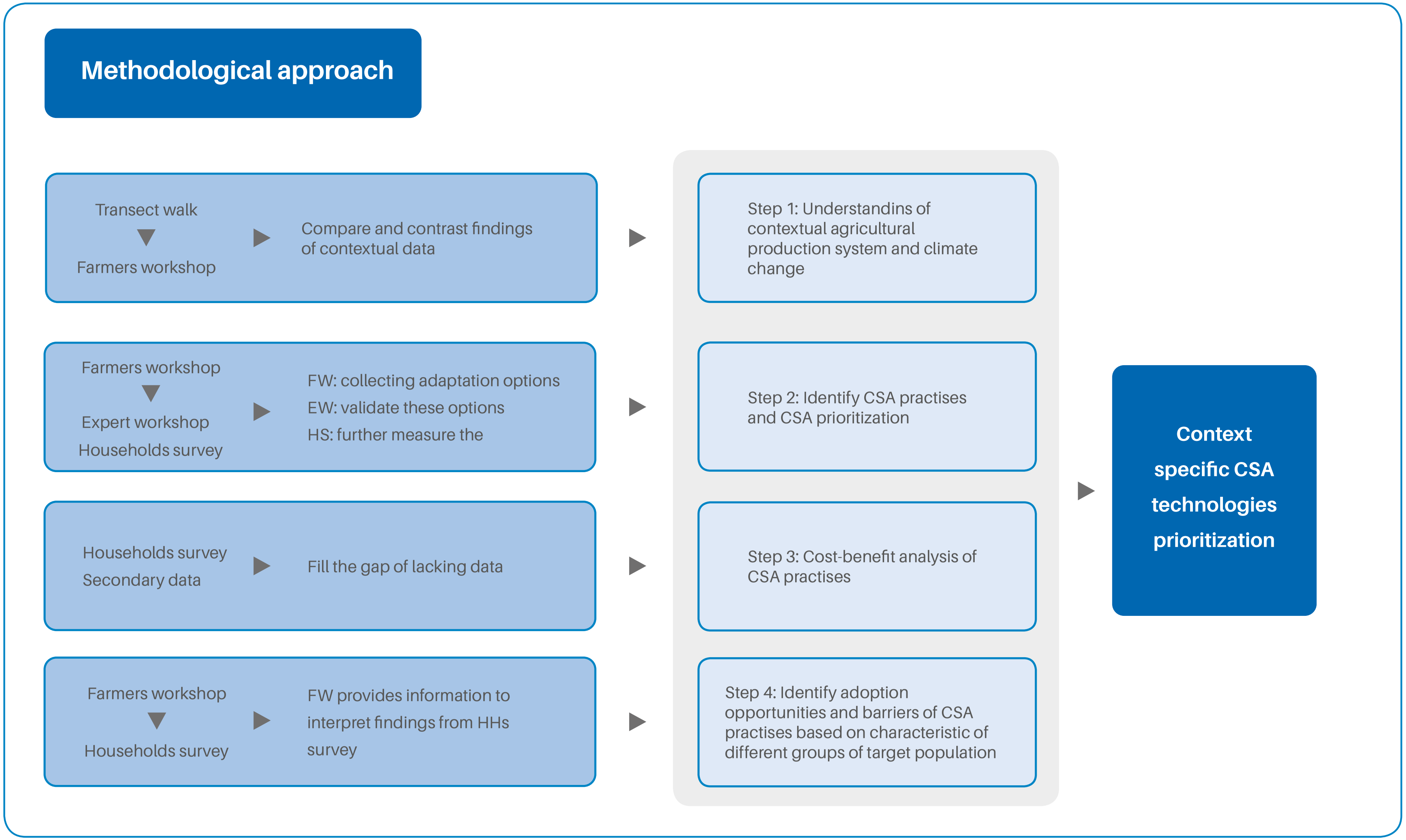


Figure 10. Summary of methodological approach and research tools adopted in the study

2. Study sites

Our study was conducted in Tra Vinh and Ben Tre provinces, where AMD is operating. Tra Vinh covers an area of 2341 km^2, with a population of 1028 million, 30% of which are ethnically Khmer, while Ben Tre has an area of 2315 km^2, with a population of 1 262 million. The two provinces share similar climatic conditions, receiving rainfall averaging 1250–1500 mm annually. Tra Vinh and Ben Tre both experience two seasons, rainy and dry, with the rainy season falling between May and October and the dry season occurring between November and April.

Five communes (Long Son, Ngu Lac, Huyen Hoi, Long Thoi and Thanh Tri) were selected based on their socioeconomic indicators, agroecological zone and level of salinity in the soils (table 6). With consultations from AMD's project coordination unit in both provinces, selected communes were considered as representative of the regions. Three communes: Long Son, Ngu Lac and Huyen Hoi belong to Tra Vinh province and two other communes: Long Thoi and Thanh Tri belong to Ben Tre province (figure 11).

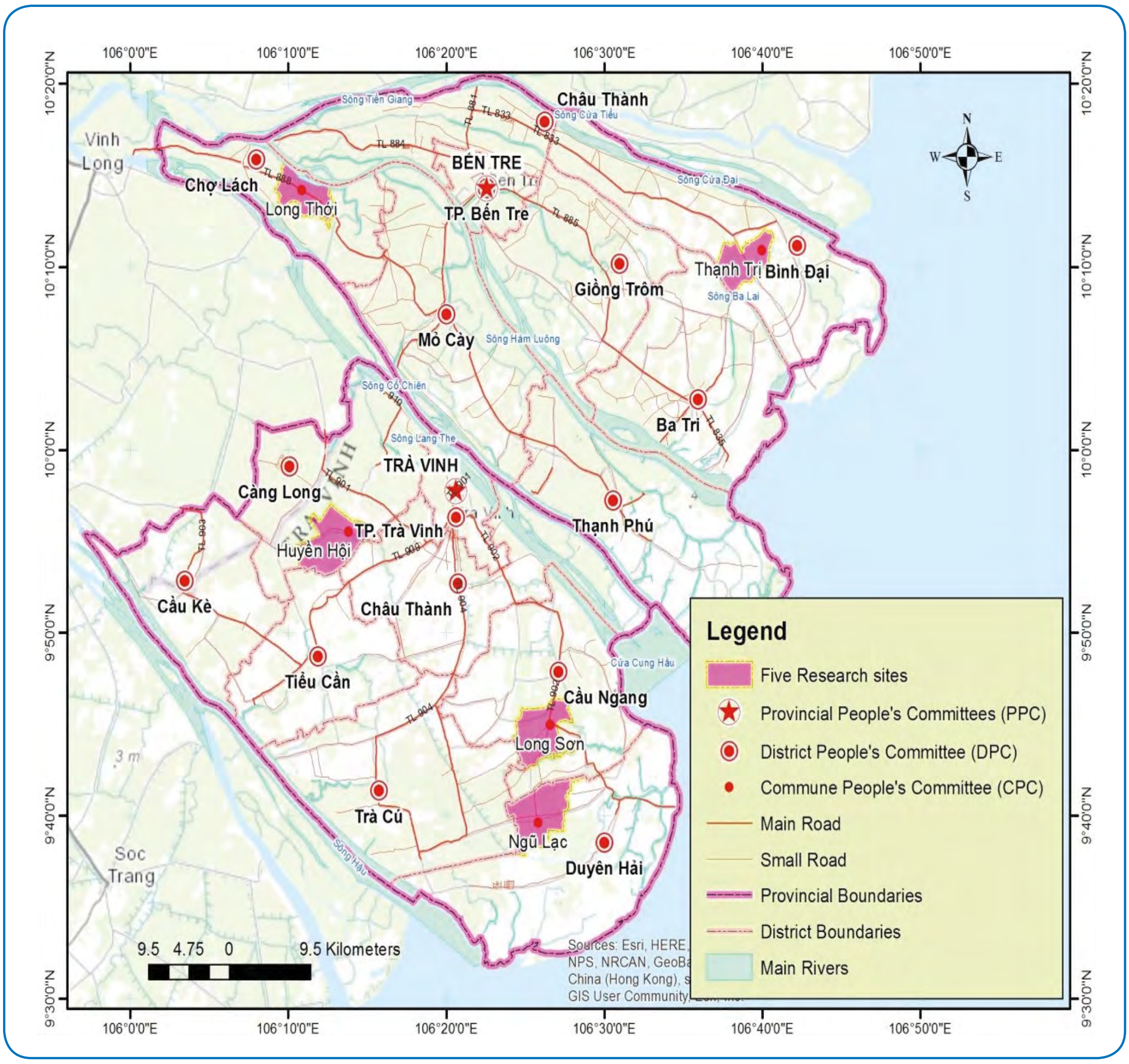


Figure 11. Map of study sites in Tra Vinh and Ben Tre

Table 6. General desciption of the study site

Province	Commune	Population (person)	Ethnicity-Khmer (%)	Poverty rate (%)	Salinity level	Agro-ecological zone
Tra Vinh	Ngu Lac	18,604	64.5	18.2	High	Saline water -brackish water
	Long Son	11,440	50.0	32.5	Medium	Saline water-brackish water-fresh water
	Huyen Hoi	17,824	9.7	14.3	Low	Fresh water
Ben Tre	Long Thoi	16,766	-	7.7	High	Saline water -brackish water/ Fruit tree
	Thanh Tri	8,192	-	14	High	Saline water -brackish water

Source: Secondary data, 2015.

3. Data collection

Transect walk

Transect walks were conducted in conjunction with farmers' workshops. Transect walks consisted of a member of the research team walking through the area accompanied by communal extension officers. In some communes, due to the unavailability of the communal extension officers, farmers from the area were consulted for the necessary information. The observations made and information gathered from the transect walks focused on crop diversity, soil types and typography, infrastructure and socioeconomic indicators (e.g. farm size, markets, land management, natural resources). The information was later used to draw a map to provide an overview of local conditions of the research area.

Farmers' workshop

The farmers' workshops were conducted in the form of focus group discussions, based on climate-smart agriculture rapid appraisal (CSA-RA) methodology for CSA prioritization (Mwongera et al 2015). The main objectives of the workshops were to capture the local context for agricultural production systems and climate impacts and to identify the adaptation options responding to highlighted challenges (figure 12). Gender aspects were taken into account by dividing up the groups for information collection. A total of 5 farmers' workshops were organized at the communal level, with each workshop hosting approximately 30–40 participants, including both men and women.

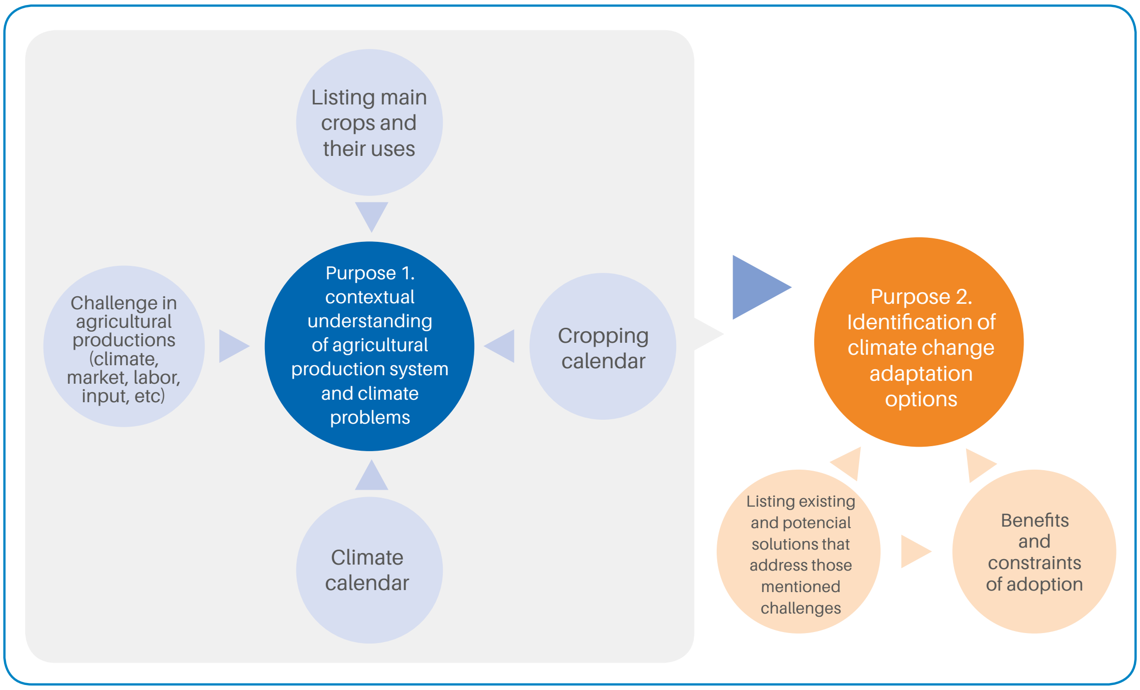


Figure 12. Overview of activities and purposes of farmers' workshop

Farmers' workshops began by asking farmers to name the main crops they grew and their uses, leading to the identification of the five major crops in the commune and the gender roles associated with each crop's production. The aim of this activity was to understand which crops were most important for farmers and should be focused on, as well as identifying the main actors in crop production activities. Participants were each provided with five blue cards to cast their vote in order to select the five main crops from the previously complied list. The highest number of cards cast identified the definitive list of five major crops. A follow-up question on gender roles in crop production was asked. In this activity, pink cards were used to represent a dominant women's role and blue cards were used to show a dominant men's role. For each of the mentioned crops, farmers were asked to raise the blue or pink cards, depending on their perception.

Starting with the master list of crops in the plenary, farmers were later arranged into smaller groups by gender to discuss cropping calendars, activities by crop during the production cycle, labour division between men and women and vulnerability during cropping cycles in normal years and years with high climate variability. Historic extreme events and their impacts were also recorded. This exercise generated contextual information for the study area, including agricultural production customs and habits, climate concern and periods of vulnerability.

The final session of the participatory workshop involved a guided discussion on the main practises and key challenges related to: climate variability, market access, input availability, access to credit, land access, pests and diseases, and seed supply. From these challenges, farmers were asked to provide their coping strategies and outline existing and potential solutions. CSA practises were then identified. For each practise, farmers were asked to raise their hand if they had adopted the practise. Reasons and constraints of adopting practises were discussed between adopters and non-adopters.

Expert workshop

An expert workshop was held at interprovincial level with the key aim of validating information collected from farmers' workshop on a broader scale. A total of 30 participants representing DARD, DONRE, people's committees of the selected communes, universities and NGOs were selected based on their relevant experience and knowledge of the topic.

Preliminary results from farmers' workshop were presented and discussed. The attending experts were asked to provide their opinions on the results of farmers' workshop. Given that local experts had a broader view on local area, we asked them to validate the benefit and wide-scale adoption probability of practises collected through the farmers' workshops. Indicators of technical feasibility, complexity, applicability, profitability, sustainability and market accessibility were used to assess practises. Experts were also asked to list additional indicators for assessment and any supplementary CSA practises, if any before the validation..

Household survey

A two-stage cluster sampling procedure was applied where a village-level sampling frame was constructed based on the number of households. At the first stage, 5 villages were randomly selected using the probability proportionate to size method (Carletto 1999), resulting in larger villages having a higher probability of being selected than smaller villages. A total of 35 households were randomly selected in each of the selected villages using village-level household lists (table 7). However, when conducting the survey, the number of households available in each commune varied slightly (1–2 household's difference). In total, the data set consisted of 170 households.

Table 7. Survey sample design

Province	Commune	Sample size
Tra Vinh	Long Son	36
	Ngu Lac	35
	Huyen Hoi	34
Ben Tre	Long Thoi	32
	Thanh Tri	33
	Total sample	170

The main purposes of the survey were: to re-assess and compare findings of contextual information at household level, to further measure the magnitude of CSA practises and to identify adoption opportunities and barriers of different population groups (figure 13). Topics covered by the survey were structured based on each purpose, ranging from demographic, socioeconomic data, land uses and tenure, food security and vulnerability, climate events, to benefits, awareness and adoption of agricultural practises.

Purpose 1 | **Re-assessment and comparison of contextual information**

- Land uses and tenure
- Cropping system
- Food security and vulnerability
- Adverse weather events and climate change

Purpose 2 | **Futher measure and exploration of benefits, awareness and adoption of identified adaptation options and responses**

- Agricultural practises and activities
- Cost and benefit of agricultural practises

Purpose 3 | **Identification of adoption barriers of target population**

- Demographic information
- Education
- Assets and properties
- Income sources
- Credit access

Figure 13. Structure of household survey

4. Data analysis

Mixed methods data analysis

Qualitative data from farmers' workshops and from experts' workshops were summarized, transcribed and grouped into different topics using descriptive and interpretative content analysis.

Quantitative data from household surveys were encoded and statistical analysis was conducted using SPSS software. Both parametric and non-parametric tests were used in the analysis.

The analysis of qualitative and quantitative data was compared and contrasted to produce an interpretation of the main findings.

Cost and benefit analysis

Cost and benefit analysis (CBA) was conducted to better understand the economic and environmental trade-offs of adopting CSA practises. A CBA tool was developed for CSA practises in tropical agricultural systems, using cropping systems inputs from Nicaragua, Uganda and Vietnam. The tool provided an estimation of economic and environmental profits of CSA practises in terms of: net present value (NPV), internal rate of return (IRR), payback period, sensitivity analysis, aggregated impact and adoption rate. Primary field data and secondary data on cost and benefit of practises were programmed into the tool for the CBA estimation. For the adoption rate, predictions were based on an estimated diffusion ceiling and the proportion of adoption at the beginning and at the mid-point. This information was collected from expert interviews, a literature review and household surveys.

Cluster analysis

Cluster analysis is a crucial step in exploring the adoption barriers to CSA practises of a specific population group. Given that there is heterogeneity in population features, they must be characterized and grouped in order to find out the potential scaling-up practises for each segment of the population.

In the total sample size, only the total number of rice producers was large enough for grouping (n = 103). For other crops such as fruit, vegetables and aquaculture, the number of producers was too small. Selected variables were chosen in order to measure certain factors that were identified locally as key factors for adoption of climate change adaptation measures (Zuluaga et al 2015). The variables included the income per capita, education level, household land area, number of hectares owned by the active population, proportion of income from rice and credit access. Income per capita and credit access were selected in order to estimate access to capital, which is key for the initial investment in a climate-smart agricultural (CSA) practise. The education level is a relative factor for learning capacity of new practises/technologies. The agriculture land area was selected to estimate both the size of the farming system and the investment size of the CSA practise. The hectare per active population is a proxy created to produce a relative labour availability estimated per household. The income from rice was an estimate of the economic relative importance of rice for that household.

We used hierarchical clustering and Ward's method for the analysis to minimize variance within each cluster. The number of clusters was selected with a dendrogram in order to maximize the similarity of each cluster and obtain reduced numbers of clusters with enough farmers in each cluster. Once the clusters were obtained, they were tested to verify the average statistical difference between different variables through ANOVAs.

III. Results

1. Socio-economic characteristics of the target population

The target population primarily rely on agricultural production. Figure 14 shows the income composition of households. The majority (74%) of households' income originates from the sale of agricultural products and agriculture related work, whereas non-agricultural work such as labourers, builders and social aid and remittances from migrant relatives account for only a small proportion of income.

Households' gross income ranges from USD 3600 year-1 to more than USD 5000 year-1 (table 8). However, a high level of standard deviation was found in the analysis, indicating an inequality in income distribution in the target population. There is a significant correlation (P= 3.66; sig. 0.01) between total income and total area of land worked by households. Given that agriculture accounts for a large percentage of income composition in the target population, the larger the amount of land a household owns, the more income it earns.

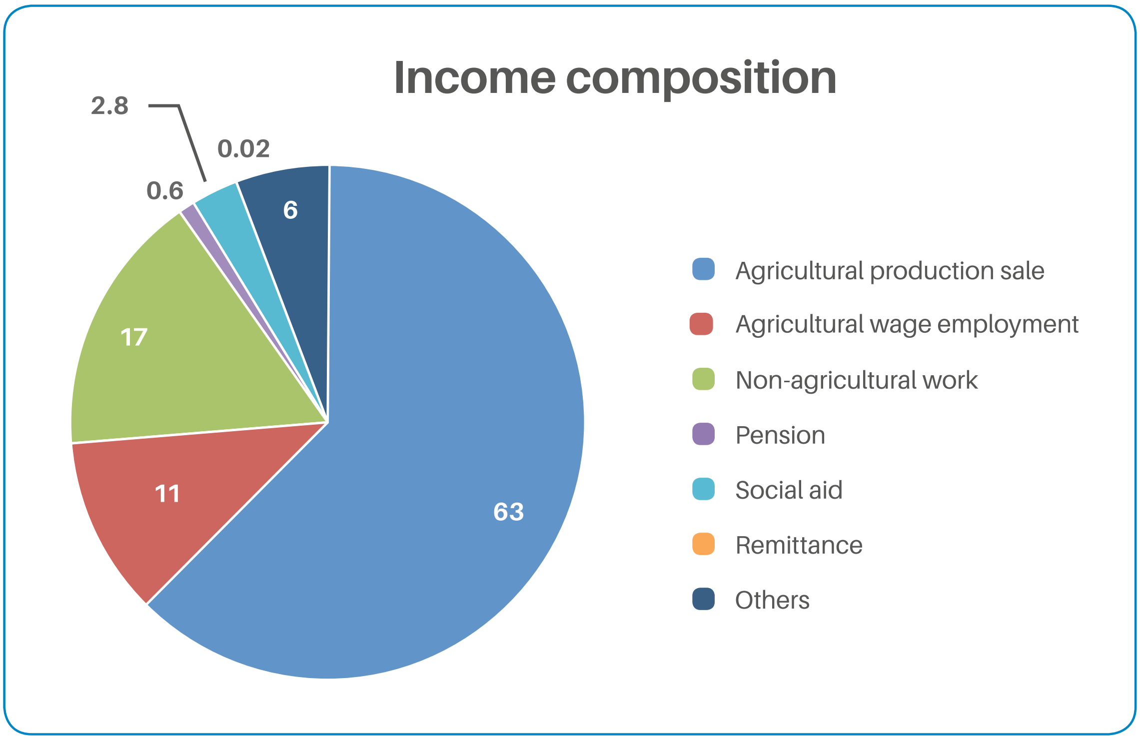


Figure 14. Income composition of target population
Source: Household survey, 2015.

Table 8. Household's total gross income and land worked per commune

Province	Communes	Total income (gross) per household		Land worked	
		US$/year		ha	
		Average	STD	Average	Std.Dev.
Tra Vinh	Long Son	4953	4672	1.1	0.9
	Ngu Lac	3448	4342	0.7	0.6
	Huyen Hoi	4177	6422	1.1	0.8
Ben Tre	Long Thoi	3664	3257	0.6	0.4
	Thanh Tri	5228	6518	1	0.6

Source: Household survey (2015).

Socio-demographic characteristics of the target population (table 9) are essential in identifying factors correlating with the adoption of CSA practises. On average, a family comprises of 4 members, of which, around two-thirds are usually under labour age. Active labour per ha in the study site is relatively dense, with a minimum of 2.6 labourers per hectare in Thanh Tri and maximum of 4.5 labourers per hectare in Long Thoi. This indicates the availability of labour in adopting practises that are either labour-intensive or less intensive.

Table 9. General socio-demographic and labor characteristic of households

Province	Commune	Household size	Household labor	Active labor per ha	Head of household	
					Age	Education*
		Average (STD)	Average (STD)	Average	Average (STD)	Average (STD)
Tra Vinh	Long Son	4.3 (1.3)	3.1 (1.2)	2.8	51.2 (10.1)	2.6 (0.7)
	Ngu Lac	4.1 (1.3)	3 (0.9)	4.2	51.1 (12.7)	2.3 (1)
	Huyen Hoi	4.3 (1.3)	3.1 (1.2)	2.8	52.4 (9.6)	2.5 (0.7)
Ben Tre	Long Thoi	3.4 (1.1)	2.7 (0.9)	4.5	53.5 (9.6)	2.4 (0.8)
	Thanh Tri	3.7 (1.4)	2.6 (0.9)	2.6	52.3 (11.8)	2.8 (0.9)

* Notes: Education levels: 1 = no school, 2 = completed elementary school, 3 = completed secondary school, 4 = high school, 5 = above high school

Source: Household survey, 2015

The majority of heads of households in the study areas were male (91%), with an average age of 51. The education level of the heads of households were relatively even across all five communes, with the attainment of a mid-to-secondary level of education. This low education level could contribute negatively to the adoption of practises with a high level of complexity.

2. Agriculture system and climate change context

Diverse agricultural systems in the study site were characterized by soil conditions, traditional customs and habits and climate conditions.

2.1. Soil conditions and cropping systems

The characteristics and conditions of soil and terrain shaped the cropping features in the research area. In the three research communes in Tra Vinh, five types of soil were categorized: Anthri cambic Aresonols (sandy dunes), Molli Salic Fluvisols (less saline soil), Areni Dystricts Fluvisols (alluvian soils on sea sand), Endo Proto Thionic Fluvisols (potential acid sulphate soils under mangrove) and Plinthi Eutric Fluvisols (stained alluvial soil). While the first three were found in both Long Son and Ngu Lac, the two soil types were distributed in Huyen Hoi only (figure 15). The Anthri Cambic Aresonols (sandy dunes) were also found in Thanh Tri (Ben Tre province). The other three types of soil in the two research communes in Ben Tre were: Epi Molli Salic Fluvisols (low and moderate salinity acidic soil), Sali Endo Orthi Thionic Fluvisols (moderate salinity acidic soil) and Bathithioni Hostic Anthrosols.

Table 10 shows the percentage of households producing crops in each commune. In general, farmers in Long Son and Ngu Lac, working under saline-brackish water conditions and with similar soil types, cultivated mostly rice, vegetables and aquaculture, while in Huyen Hoi, a fresh water commune where two different soil types were observed, specialized in rice and coconut as the main crops. Long Thoi dedicated their land to fruit only and Thanh Tri had a diversified crop system that included rice, fruit and aquaculture.

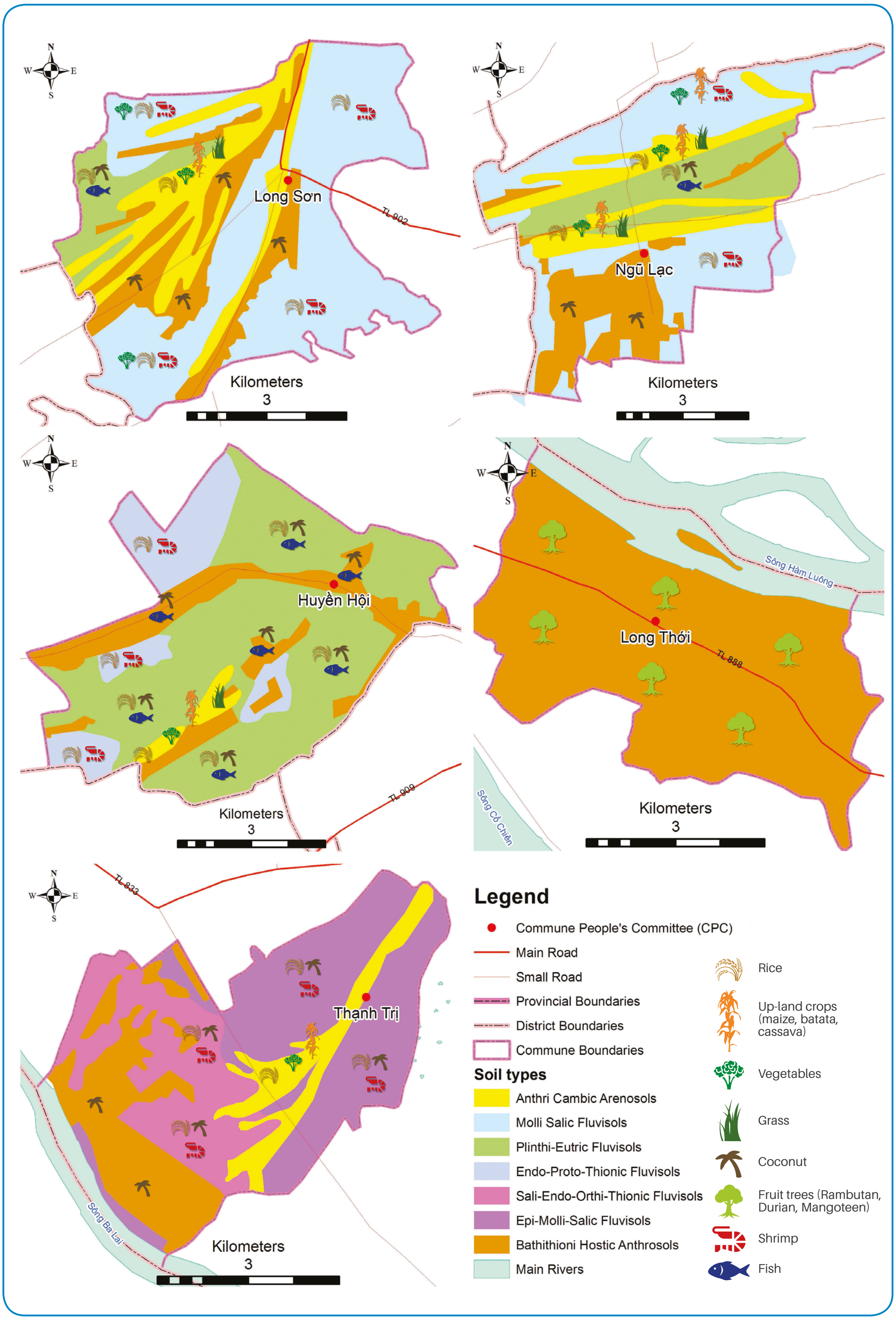


Figure 15. Map of soil types and crops distribution in the five researched communes
Source: Transect walk, 2015.

Table 10. Distribution of different crop producers in the 5 communes

Province	Commune	N (# of hhs)	Rice producers %	Fruit producers (including coconut) %	Vegetable producers %	Aquaculture producers %
Tra Vinh	Long Son	36	80.6	5.6	52.7	22.2
	Ngu Lac	35	71.4	0	42.9	34.3
	Huyen Hoi	34	100	20.6	5.8	0
Ben Tre	Long Thoi	32	0	96.9	3.1	0
	Thanh Tri	33	45.5	57.6	3	39.4

Source: Household survey, 2015.

A number of different cultivation methods for each crop were observed. Rice is usually mono cropped or rotated with subsidiary crops. With mono cropping, rice can be grown in one, two or three seasons depending on soil and water conditions. For example, Huyen Hoi and Long Son had three seasons for rice growing thanks to the good soil and abundant water sources. In the areas where water was scarce, rice was rotated with subsidiary crops that needed less water and could be grown in the dry season. All three communes in Tra Vinh had either 1-rice–2-subsidiary crops or 2-rice–1-subsidiary crop. In high terrain areas, vegetables and subsidiary crops were the most suitable crops as they required less water. Coconut was often found around residential or garden areas in Huyen Hoi and Thanh Tri, with the water ditches used for fish farming. Fruit trees in Long Thoi were grown in the gardens where land was formed by digging ditches, raised beds or converting from paddy rice. Intensive shrimp and shrimp-crab intercropping systems were mostly observed in areas that were often affected by tides.

Despite the wide variety of crops, rice was still the most important commercial and subsistent crop in all sites, except for Long Thoi where fruit trees were dominant. In Tra Vinh, vegetables and subsidiary crops such as watermelon, peanuts and bean were the alternative important cash crops of Long Son and Ngu Lac farmers while Huyen Hoi farmers depended on rice, coconut and aquaculture. In Ben Tre, fruit tree production was the main income source of Long Thoi and Thanh Tri farmers who alternate their income with more diversified crops.

The question, "who do you think of when a name of crop is mentioned?" was asked in order to assess farmers' perception of female and male participation in the cultivation of each crop (figure 16). In almost all crops, especially rice and fruit production, farmers reported that men did much more work than women. The participation of women was found to be considerable in the cultivation of subsidiary crops such as peanuts, watermelon, grass (fodder) and coconut. This indicated that female participation in agricultural production was still perceived to be relatively low.

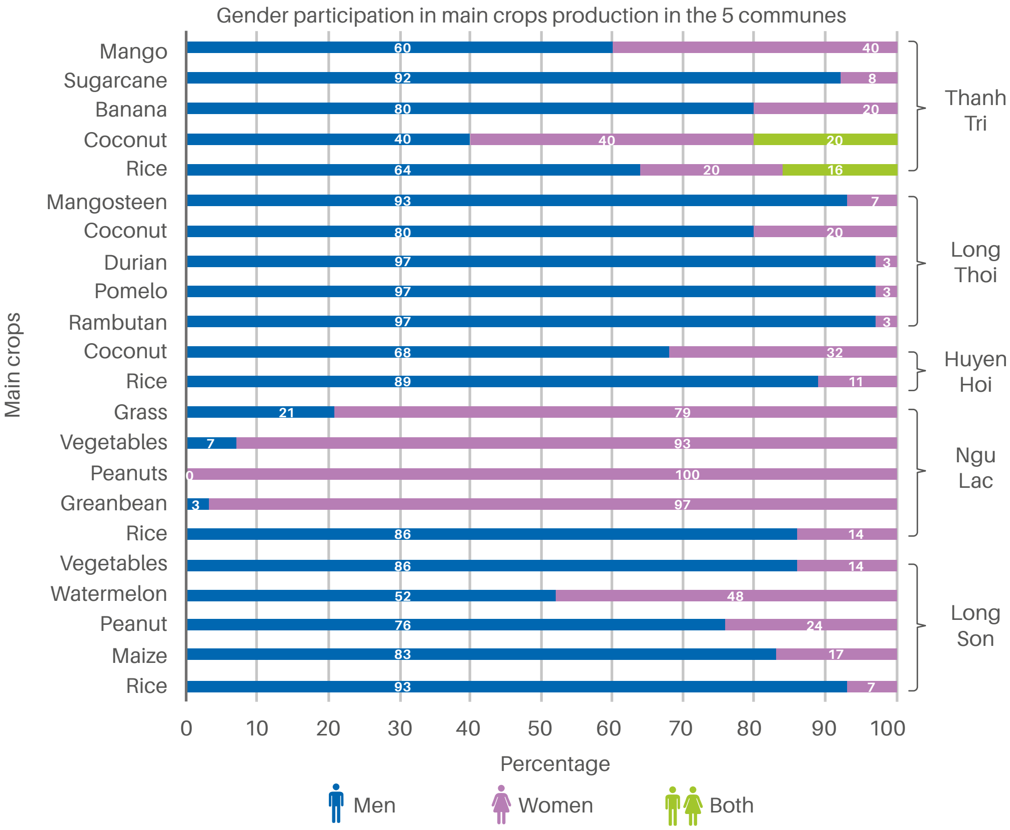
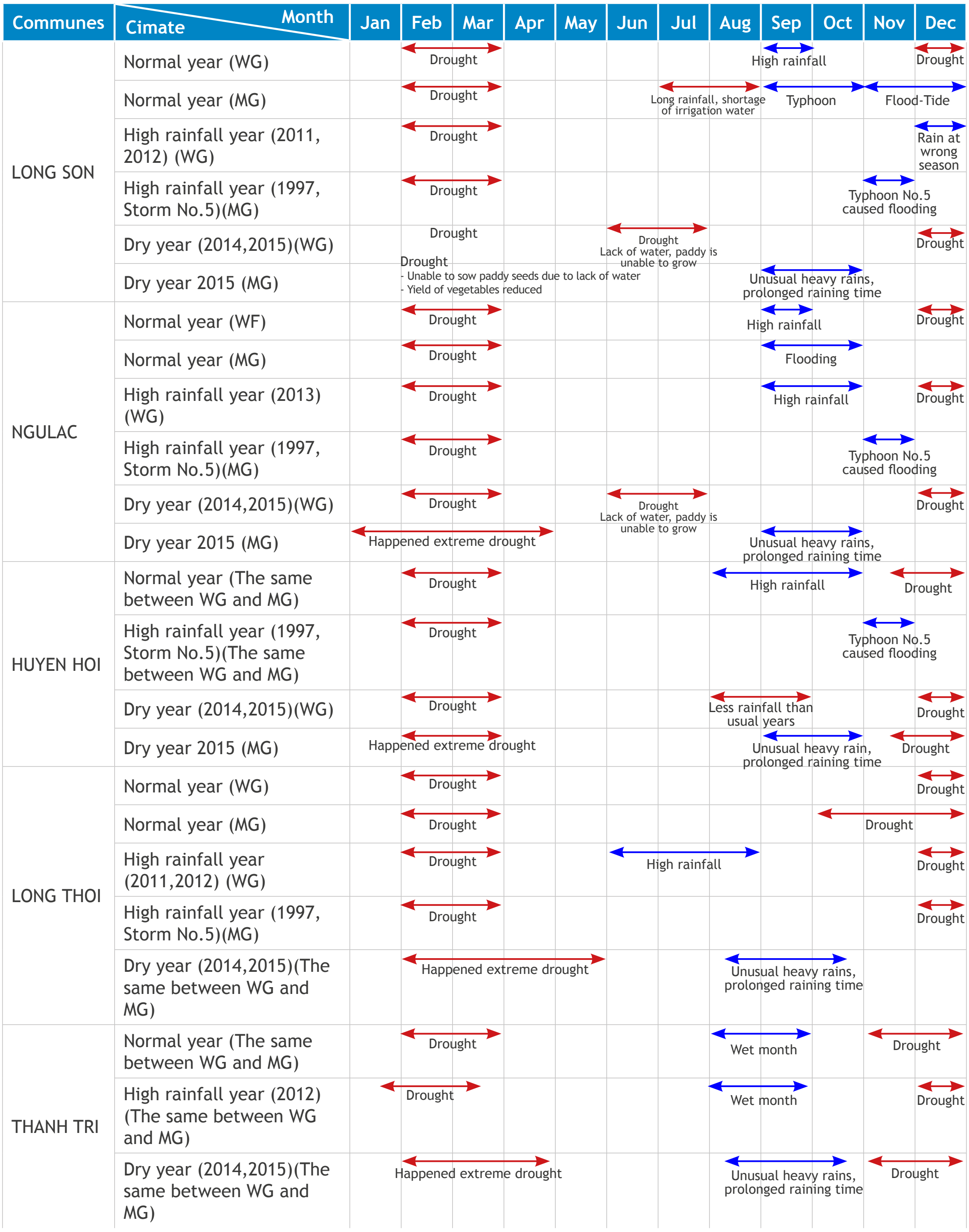


Figure 16. Farmers' perception on gender's role in main crops production in the research area
Source: Farmers' workshop, 2015.

2.2. Climate change context and agricultural production cycle

Climate change exposure based on farmers' perception showed how farmers perceived these changes in terms of their agricultural production and their coping strategy.

Qualitative information on climatic conditions and periods of vulnerability for agriculture production cycles were collected from farmers' workshops in the five communes. Figure 17 describes gender-based perceptions across the five communes of climatic conditions for normal years, as well as for wet and dry years. In general, both male and female groups reported that drought often occurred for at least 3 months in normal years, occurring in February, March and December. In dry years, droughts usually started earlier and extended for longer, by up to 6 months. In Long Son and Ngu Lac, drought conditions appeared abnormally in June and July. In a high rainfall year, the length of rain did not change significantly but increased amounts of rain were witnessed, leading to floods and typhoons in the rainy season.



Note: WG: Women Group MG: Men Group

Figure 17. Climate calendar in the research area
Source: Farmers' workshops, 2015.

Farmers cultivated crops depending on crop features and climate calendar. Figure 18 provides gender-based perceptions on the cropping calendar and labour division of the five communes.

In Long Son and Ngu Lac, the cropping calendar for common crops is similar. Rice was planted in two seasons, avoiding the drought period during February, March and December, but the rice

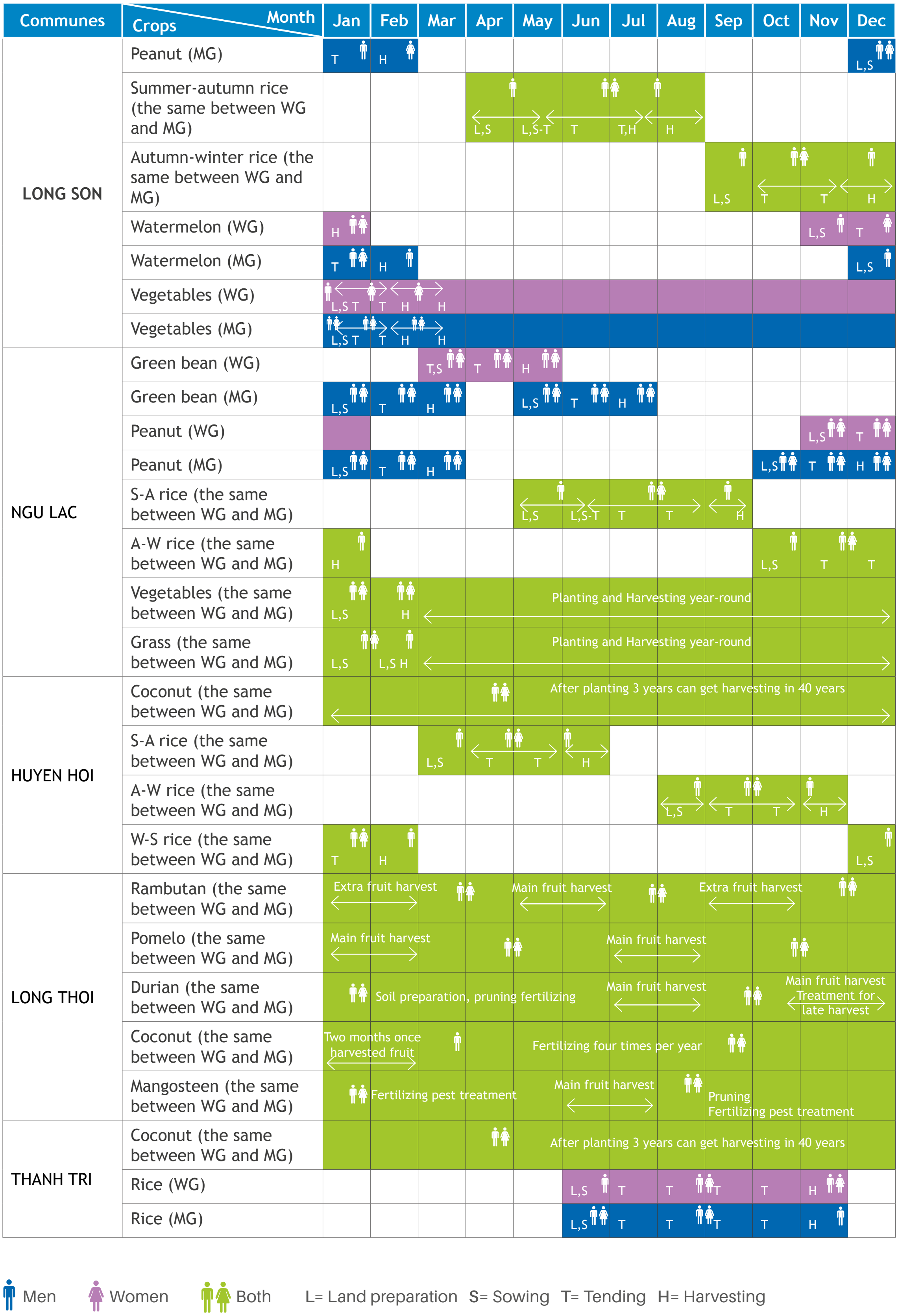


Figure 18. Gender-based cropping calendar and labour division in the research area

Source: Farmers' workshops (2015).

season in Ngu Lac started 1 month earlier. Subsidiary crops such as peanuts, green beans (Ngu Lac) and watermelons (Long Son) were rotated with rice and planted in the drought season when rice could not be grown. Vegetables were either grown as subsidiary crops and rotated with rice in drought seasons or grown the whole year round. Huyen Hoi had three rice seasons as the commune benefited from three months of rain, from August to October. In Thanh Tri, only one season of rice was reported, starting from June to November, longer than rice seasons in the other three communes. Thanh Tri's farmers used local long-time rice seeds and claimed that they could make more profit because of its higher quality, selling price and survival rate, which is higher in the case of increased salinity. It is often grown in the rainy season in brackish water conditions and transitioned into shrimp farming in the dry season. Coconut and fruit trees in Long Thoi, as perennial trees, required planting or additional planting, tending and harvesting all year round.

The division of labour at each production stage of crop gives us an understanding of gender knowledge and responsibility in crop production. The labour division in each of the production stages was reported as slightly different between men and women. In general, there was mutual agreement that men's participation was dominant in the whole production cycle of rice, while women's presence was acknowledged at the tending stage only. Women participated more in growing subsidiary crops such as peanuts, green beans, watermelons and vegetables. Both men and women participated in producing perennial trees such as coconut and fruit trees. This result also corresponds to gender's participation as shown in figure 16 above.

2.3. Challenges in agricultural production

Men and women in farmers' workshops reported alternative challenges related to climate, market access, credit access, input availability, land access, and pests and diseases. In general, farmers' climate concerns concentrated on drought, erratic heavy rain and sea-level rise. Drought and heavy rain frequently occurred in all communes, while sea-level rise was reported to be a serious problem in Thanh Tri. Drought significantly affected the production of all crops. For example, in Long Son, extreme drought led to a reduction in vegetable productivity of up to 50% and the dead loss of winter-spring rice in 2012. In non-irrigated areas such as Long Son, Ngu Lac and Thanh Tri, the consequences were tremendous due to a considerable increase in production costs for pumping, electricity and labour. The men's groups, reported salinity invasion as a significant problem, which damaged paddy rice (Long Son, Huyen Hoi) and shrimp farming (Ngu Lac, Thanh Tri). Additionally, it was reported that erratic rainfall flooded the crops, causing root rot of fruit trees in Long Thoi, reduced salinity level in shrimp ponds, resulting in disease and shrimp death. The impacts of unpredictable weather patterns were also considerable as farmers were unprepared.

The number of households to suffer crop losses due to weather events in the 5 communes is described in table 11. Drought was mentioned by many farmers in all 5 communes, especially in Long Son (75%), Ngu Lac (74%) and Long Thoi (46.9%). Erratic rain was reported as the second highest reason for farmers' crop losses. Flood, although discussed in farmers' workshops, were rarely reported in all communes except for in Long Thoi. A rise in sea level did not seem to be a concern for the farmers in the survey.

Table 11. Percentage of households suffering crop losses from weather events

Province	Commune	Occurrence of crop losses due to			
		Drought (%)	Flood (%)	Erratic rain (%)	Sea-level rise (%)
Tra Vinh	Long Son	75	2.9	32.3	6.1
	Ngu Lac	74	6.1	8.8	12.1
	Huyen Hoi	23.5	0	23.3	0
Ben Tre	Long Thoi	46.9	17.2	32.3	6.5
	Thanh Tri	12	3	22.6	3

Source: Household survey, 2015

Most of the workshop participants reported limited access to markets, with most trading carried out through middlemen without contracts, resulting in unsecured product prices that were lower than the real market price. A deficit in information about markets, paired with the lack of connections between farmers and real buyers were additional problems that restricted the bargaining capacity of farmers.

Only limited lines of credit were available in the study sites; smallholder farmers had difficulty accessing big loans through commercial banks as they require collateral. Small loans with favourable interest rates were accessible to the poor or marginal poor through VBSP but could not be used for big agricultural investments. There were informal sources of credit available including private lenders and loans offered with an illegally high interest rate that farmers could not afford to repay. Agricultural input dealers often loaned inputs to farmers. Farmers borrowed funding for agricultural inputs such as fertilizer, pesticide, seeds, etc. for their crop production and paid it back after harvest at higher than normal prices. No microfinance institutions were available in the area.

The challenges of input availability consisted of a lack of labour, escalating prices of agricultural inputs and unreliable quality of inputs. In Long Son, the presence of youth labour in agricultural activities was limited as they tended to migrate to larger cities to seek out job opportunities. The price of agricultural inputs offered by dealers were claimed to be higher than normal. In addition, due to limited access to information to a wide range of varieties, farmers often found it difficult to select products of high quality for a reasonable price. In Long Thoi, bogus fertilizers were recorded, which resulted in lower than expected fruit production in many households in the region.

While women groups confirmed that only the poor had limited access to land, men reported that their land area was too small for cultivation. The problem was encountered in the two communes in Ben Tre. In Tra Vinh, Ngu Lac and Huyen Hoi, farmers reported no serious concerns about land access but farmers in Long Son were worried about degraded land due to acidity and salinity intrusion.

There was a significant increase in pests and diseases in terms of variety and quantity. Rice, maize and vegetables were affected by emerging pests, of which farmers lacked information for control and prevention, leading to great losses. Disease in shrimp and livestock also caused huge financial damage.

3. CSA practises prioritization

3.1. CSA practises by farmers

The prioritization process of CSA practises was based on a bottom-up approach in which farmers' perceptions play an important role. In order for farmers to identify CSA practises, multiple questions were asked, starting from agriculture and climate context and conditions, to challenges and solutions. A number of CSA options were identified through farmers' workshops as illustrated in table 12. Additionally, the benefits, constraints and problems addressed concerning the adoption of the practises were also summarized.

In general, there were three practises that focused on solving problems associated with drought: use of plastic mulching, changing cropping systems and use of drip irrigation. Two practises tackled problems posed by sea-level rise, which increases salinity in soil by adopting salt-tolerant rice varieties or implementing a rice-shrimp rotation. Only one practise for preventing the impacts of heavy rain was discussed. Organic fertilizer was mentioned when asked about practises for increasing economic efficiency of production. Although the practises were named, their adoption was limited. Lack of capital was cited as a key adoption constraint as the practises often required high investment. Farmers in Long Son, Ngu Lac and Huyen Hoi commune adopted and proposed more CSA practises than other communes because the topography, soil conditions and crops were more diversified. Long Thoi's farmers used with fewer CSA practises, as the area was less diverse in terms of crops and mainly concentrated on fruit trees. In Thanh Tri, farmers' major concern was the intrusion of salinity; they grew salt-tolerant rice varieties and carried out shrimp farming.

Table 12. Number of people selected CSA practises with women and men groups in 5 communes

ID	Selected practises	Target crops	Adopters		Benefits	Addressed climate problems	Contraints for adoption
			Men	Women			
1	Plastic mulching	Vegetables, fruit	35	27	Save waters by reducing evaporation; reduce pest and disease	Drought/Pest & disease	No
2	Drip irrigation	Vegetables, fruit	1		Save waters for drought season	Drought	High investment
3	Green house	Vegetables	5	4	Prevent vegetables from heavy rain, wind and storm; reduce pest and disease	Heavy rain and storm/ Pest and disease	High investment
4	Salinity resistant variety	Rice	27	23	Plant in salty region to avoid yield loss	Sea-level rise	
5	Change cropping system	Rice, vegetables	31	25	change to plant crops which require less water in drought season	Drought	No
6	Crop-aquaculture rotation/ intercropping	Rice, shrimp, coconut, fish	3	1	Aquaculture in flooding season, manure from shrimp increase organic matter in soil for rice production in next season	Flooding, sea-level rise	High investment and high risk
7	Organic fertilizer	All	18	7	Economic efficiency		No

Source: Farmers' workshops (2015).

3.2. CSA practises by local experts

A consensus in identifying CSA practises and their benefits amongst farmers and experts was found. Experts with a broader view of the region came up with a longer list of practises. Almost all practises identified by farmers, such as drip irrigation, plastic mulching, salinity resistant varieties, organic fertilizer, aquaculture-crop rotation was in the top-10 practises as ranked by experts (table 13). The "greenhouse" practise was not on the list due to its unsuitability for the population of the region.

According to experts, drip irrigation and plastic mulching practises were of the highest priority, with 96% of votes agreeing with their profitability, sustainability and their potential to solve drought problems while not requiring a high level of complexity. The salt-resistant variety of rice was ranked as the third highest prioritized practise because of its sustainability, profitability

Table 13. CSA practises ranked by experts

ID	Selected practises/ Selection criteria	Objects	Votes (%)	Technical feasibility	Complexity	Applicability	Profitability	Sustainability	Market accessibility	Credit accessibility
1	Drip irrigation	Vegetables, fruits	96	High	Medium	Medium	High	High	Medium	Medium
2	Plastic mulching	Vegetables, fruits	92	High	Low	High	High	High	Medium	Medium
3	Salinity resistant variety	Rice	79	High	Medium	High	High	High	High	High
4	Alternative wetting & drying	Rice	58	High	Medium	Low	Medium	High	Medium	Medium
5	IPM	Rice, fruit, vegetables	58	High	High	Medium	High	High	High	Medium
6	Organic fertilizer	all	58	High	Low	Medium	Medium	High	High	Medium
7	Micro-biotic finishes	all	54	High	Low	Medium	High	High	Medium	Medium
8	Aquaculture - crop rotation	Rice, shrimp	54	High	High	High	High	High	High	High
9	1 must 5 reduction	Rice	50	High	Medium	Low	High	High	High	Medium
10	Crop-livestock intercrop		50	High	Medium	Medium	High	High	High	High
11	Change cropping system	Rice, vegetables	50	High	High	Medium	High	High	High	Medium
12	Aquaculture - crop intercropping	Fish, rice	46	Medium	Medium	Medium	Medium	High	Medium	Medium
13	Convert from annual crop to perennial crop		42	High	High	Medium	Medium	High	Medium	High
14	System of Rice intensification (SRI)	Rice	37	Medium	High	Medium	Medium	High	Medium	Low
15	Convert from perennial crop to annual crop		33	High	Medium	High	High	High	High	Medium
16	Recycle agricultural wastes	All	25	Medium	Medium	Low	Medium	Medium	Low	Medium

Source: Experts' workshop (2015).

and its high market value compared with normal varieties. However, experts claimed that the variety should be tested on local soil before being widely adopted. IPM, organic fertilizers and the use of microbiotic finishes were among the practises that did not require a high initial investment, were of high market value, reduced input costs, but were labour intensive, were also ranked in the top seven. The rice-shrimp rotation system, although it was proven to be effective and highly profitable in literature reviews, ranked eighth due to its high complexity and risks. Shrimp was claimed to be very difficult to raise and easy to loose. 1 must 5 reduction or 3 reduction 3 increase is a practise which requires rice farmers to use certified varieties, reduce the number of seeds, chemical fertilizers, pesticide and water used. The practise was widely promoted across the country including in the study sites. According to Tra Vinh experts, although this is a labour intensive practise, they planned to make it one of the requirements for rice cultivation meant for export.

According to experts, market access was the most important issue when choosing practises to scale-up. Although a practise could help a crop to effectively adapt to the climate and increase its yields, it was still not chosen for adoption if its markets were not guaranteed. Local conditions and cultivation habits of the area were other factors taken into consideration; as soil types were diverse, research on suitable crops for each type was carried out before wider application.

3.3. Magnitude of CSA practises: awareness and adoption

Farmers' awareness and adoption of CSA practises identified in farmers' and experts' workshops was obtained through the household survey. Table 14 presents the awareness and adoption of the practises for target crops. There was a lack of awareness of adoption of all these practises.

Rice producers seemed to know more about salt-tolerant varieties than the other three practises. The 1 must 5 reduction practise, although was promoted few years ago, was not very popular in the study sites.

Two practises aimed at coping with effects of drought on fruit and vegetables – drip irrigation and plastic mulching – were better known by vegetables producers than by fruit producers and were not widely adopted.

For those practises that could be applied to all crops, organic fertilizer was the most well-known and adopted practise in all 5 communes. IPM was more popular in the communes that specialized in rice (Huyen Hoi) and fruit (Long Thoi) production and the other two were less apparent and rarely used by farmers.

The limited awareness and adoption of microbiotic residues and recycling of agricultural waste products explained the absence of the practises in farmers' workshop. Integrated pest management (IPM) was more popular with rice and fruit producers but they were not mentioned in farmers' workshop. This could be because farmers did not consider IPM to be an adaptation practise. Benefits of the IPM mentioned by farmers in survey were mostly based on economic

Table 14. Awareness and adoption of CSA practises

Crops	N	Practises	Aware (number)	Adopt (number)
Rice	103	1 must 5 reduction	35	10
		Salt tolerant variety	47	10
		Drought tolerant variety	34	7
		Monocropping to crop rotation	28	6
Vegetables	37	Drip irrigation	21	8
		Plastic mulching	21	11
Fruit	59	Drip irrigation	14	3
		Plastic mulching	14	5
All crops	170	IPM	80	68
		Organic fertilizer	119	65
		Micro-biotic residues	31	11
		Recycling agricultural waste products	80	23

Source: Households survey (2015).

efficiency (17.5% of adopters), reduction in pests and diseases (10%) and increase in product quality (5%).

Adopters of CSA practises were asked to identify the benefits of adoption. As many as 62% of them stated that CSA practises brought in more income for their household. Other benefits mentioned by a small percentage of farmers were: adaptation to the climate, reducing pests and diseases, labour saving and increasing the quality of the product.

4. Cost-benefit analysis of CSA practises

In this section, we provide a cost-benefit analysis of the CSA practises that were mutually agreed upon by both farmers and experts. These practises included use of: drip irrigation, plastic mulching, salinity resistant rice variety, organic fertilizers, aquaculture-crop rotation and changing the cropping system.

The net incremental benefit of the practise was presented in NPV; farm unit for the analysis was 1 ha and the discount rate was 9%, the same as the interest rate of local VBARD, the main credit source of farmers in the area. The assumptions made from the analysis were either based on the household survey or on the literature review. The scenario analysis was based on the life cycle of new adopted technologies/equipment or perennial trees. The scenario analysis for practises for vegetables and fruit was made over a 9-year period and the practises for rice was made for a 10-year cycle.

Inputs were collected from different sources including household surveys, farmers' and expert workshops and secondary data and literature reviews. The inputs used for calculation are presented in table 15.

Table 15. Summary of inputs used for CBA

Variables	Unit	Value	Price (VND)
Current crops yield			
Winter rice	Kg/ha	4,750	5,500
Summer rice	Kg/ha	5,300	5,000
Rice by-products	Kg/ha	11,875	1,500
Sugarcane	Kg/ha	65,000	900
Watermelon	Kg/ha	29,000	5,000
Rambutan	Kg/ha	18,000	12,000
Coconut	Kg/ha	10,000	5,500
Peanuts	Kg/ha	1000	10,000
Shrimp	Kg/ha	450	120,000
Investment/Establishment			
Ploughing	Ha	1	150,000
Tools	Ha	1	65,000
Weeding equipment	Ha	1	250,000
Transplanting/seeding	Set	1	8,000,000
Harvesting	Ha	1	150,000
Agricultural inputs			
Rice seeds	Kg	na	12,000
Watermelon seeds	Gram	na	7,500
Coconut seedlings	Kg	na	20,000
Sugarcane seeds	Kg	na	1,000
Peanuts seeds	Kg/ha	240	10,800
Shrimp seed	Each	na	60
NPK	Kg	na	12,000
Urea	Kg	na	11,000
Phosphate	Kg	na	6,000
Potassium	Kg	na	12,000
DAP	Kg	na	16,000
Pesticides	Ha	na	1,800,000
Manure	Ton	na	200,000
Hired-labor	Man-day	na	120,000
CO_2	Kg Tons	na	112,500*

Other costs could be included depending on crops and practises such as pond reconstruction, transportation.
Note:
- na: not applicable. Value depends on practises and crops.
- 1 USD = 22,500 VND.
- * Average price of t CO_2 in Vietnam in 2013.

Source: Households survey (2015).

The practises are presented below, including description, CBA table and discussion.

Practise 1: Drip irrigation

a. For watermelon

Photo credit: Lan LN.

Description

A drip irrigation system addresses the issues of water scarcity during the drought season by using water more efficiently. Farmers use rubber pipes to convey water. Holes are bored into the pipes at the base of plants, thus water does not spread everywhere, but drips in directly to where it is needed. This results in fewer weeds and less herbicide usage. The pipe can be used for up to 9 years.

Assumption: from household survey, we assumed that the yield of watermelon would be increased by 5% and labour cost of watering and weeding could be reduced by 5%.

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	Before	After
	966	70	3	327.6	Watermelon without drip irrigation	Watermelon with drip irrigation
Aggregate analysis CBA tool summary	Total area of watermelon	Current adoption rate	Adoption rate	Aggregated NPV	Period	
	23.8 ha	24%	80%	$37,738	10 years	

Source: Households survey (2015).

Discussion

The drip irrigation for watermelon practise can be used in the context of an extreme lack of freshwater and drought in the Mekong Delta region. However, the initial investment in the first year is relatively high (USD 327) compared to the benefit gained after 10 years (USD 966). It takes 3 years for the practise to reach break-even point. In the total area of vegetables, with a current adoption rate of 24%, after 10 years, it is expected that 80% of total area of vegetables would be impacted, avoiding a loss of USD 37 738 for the community in the study site.

b. For rambutan

Photo credit: Phi Phi.

Description

Plastic pipes are used in for this practise. Holes are bored into the pipes at the base of plants. This practise addresses the issues of water scarcity during the drought season by saving water and it also reduces root rot of fruit trees. The pipes can be used for 9 years.

Assumption: from household survey, we assumed that yield of rambutan would increase by 3% and labour cost of watering and weeding would reduce by 5%.

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	Before	After
Value	4,200	77	3	1,261	Rambutan without drip irrigation	Rambutan with drip irrigation
Aggregate analysis CBA tool summary	Total area of fruit	Current adoption rate	Adoption rate	Aggregated NPV	Period	
	29 ha	5%	70 %	$302,533	10 years	

Source: Households survey (2015).

Discussion

The practise of drip irrigation for fruit in general, or in this case, for rambutan, brings good financial return but requires a high investment (USD 1261), which takes 5 years to payback. The tool estimated that 70% of the total 29 ha would be impacted by the practise after 10 years, bringing a total benefit of USD 302 533 for total fruit producers in the sample size.

Practise 2: Plastic mulching: watermelon

Photo credit: Pham Anh Hung.

Description

Plastic mulch layers are used to cover land for vegetables and can be used in 1 year. Plastic mulch can save water by reducing evaporation and reduce incident of pests and diseases. This practise is annual practise and the benefit is estimated for 9 years for comparison with drip irrigation practise for watermelon.

Assumption: Using practise, yield of watermelon could be increased by 3% and pesticide cost could be reduced by 5%.

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	Before	After
	1,045	93	3	249	Watermelon without plastic mulching	Watermelon with plastic mulching
Aggregate analysis CBA tool summary	Total area of watermelon	Current adoption rate	Adoption rate	Aggregated NPV	Period	
	23.8 ha	32%	71%	$27,866	10 years	

Source: Households survey (2015).

Discussion

The plastic mulching practise is another option for farmers to tackle drought. It brings a good return (USD 1044) with a lower investment cost compared to the drip irrigation system. The IRR is also higher than the drip irrigation practise. At the community level, the practise would generate benefits of up to USD 27 866 for 71% of a total area of 23.8 ha of watermelon. However, it cannot solve the problem of water shortages or drought as effectively as drip irrigation does. In the case of extreme drought, there would be higher risk of losing a harvest when using plastic mulching compared to using drip irrigation.

Practise 3: Salinity-resistant rice variety

Source: CLRRI.

Description

A salinity-resistant rice variety, OM6976, a hybrid from CUU Long Delta Rice Research Institute, is used in the area affected by increased salinity level. The variety has a salt tolerance of 3–4%.

OM6976 is currently proposed to replace IR 40404, a local variety with a low quality of product and a low tolerance level for pests and salinity.

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	Before	After
Value	3,001	224	2	19.6	IR 40404	OM6976
Aggregate analysis CBA tool summary	Total area of rice	Current adoption rate	Adoption rate	Aggregated NPV	Period	
	81	9.1	94%	$660,531	10 years	

Source: Households survey (2015).

Discussion

Use of a salinity-resistant variety is essential, especially when salinity levels are predicted to rise in Tra Vinh, Ben Tre and the whole Mekong Delta region. The net benefit and internal rate of return of the practise is estimated to be high, with acceptable investment costs. The practise will be adopted by 94% of a total of 81 ha after 10 years, generating a benefit of USD 660 531.

However, the most recent report of the Department of Agricultural and Rural Development (DARD) of Tra Vinh province in 2016 indicated that OM6976 grown in winter 2015–2016 was destroyed due to extremely high levels of salinity. Thus we need to find another variety or options for the area.

Practise 4: Organic fertilizer

Source: Pham Anh Hung.

Description

Use of organic fertilizer is a CSA practise that helps to improve soil quality, reduce GHG emission and bring economic efficiency to production. In practise, a microbiotic ingredient, (Trichoderma) was used to make organic fertilizer from rice straw and animal's compost.

Organic fertilizer can be applied to many crops. In this estimation, organic fertilizer used in rice production was analysed.

Assumption: using organic fertilizer could reduce 2.8 t CO_2/ha (Trinh et al 2013).

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Social NPV	Social IRR	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	US$	%	Before	After
Value	2,055	Na	Na	-64.4	3,350	na	Rice without organic fertilizer	Rice with organic fertilizer
Aggregate analysis CBA tool summary	Total area of rice	Current adoption rate	Adoption rate	Aggregated NPV			Period	
	81	50%	92%	$223,482			10 years	

Source: Households survey (2015).

Discussion

The initial cost of organic fertilizer implementation is 64.4 US$ less than existing practise which use chemical fertilizer. The practise could generate a relatively high benefit (USD 2055) and a social benefit of USD 2153. As the current adoption rate is 50%, it is estimated that after 10 years, 92% of 81 ha of rice would be adopted and the aggregated benefit could be up to USD 223 482.

Practise 5: Aquaculture – crop rotation (rice – shrimp)

Photo credit: TL.

Description

The practise addresses the issue of increased salinity in soil. Rice is planted in the rainy season and shrimp are raised in the drought season. The practise helps to increase soil moisture from shrimp's waste and reduce pesticide use for rice.

GHGs emission from changing rice-rice to rice-aquaculture is estimated to reduce by 4.9 t CO_2/ha in 2015 (Trinh et al 2013).

CBA analysis:

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Initial investment	Social NPV	Social IRR	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	US$	%	Before	After
Value	3,580	35	5	868	3,751	36	2 rice season	Rice-shrimp rotation
Aggregate analysis CBA tool summary	Total area of rice	Current adoption rate	Adoption rate	Aggregated NPV			Period	
	81	8%	44%	$317,663			10 years	

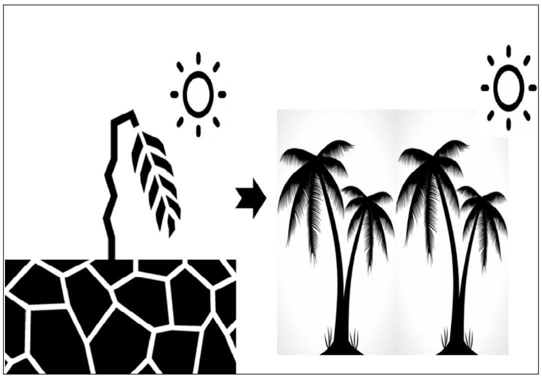
Source: Financial analysis AMD Tra Vin.

Discussion

A rice-shrimp rotation is one of the adaptation options in the area affected by salinity intrusion in the Mekong Delta when winter-spring rice season could not be grown. This practise is risky, as it requires high investment cost (USD 868) compared to a benefit of USD 3580 generated after 10 years. It requires a high level of complexity as shrimp are difficult to raise and it is relatively easy to suffer major losses due to disease. This is not an option for poor households unless there is financial support.

Practise 6: Change cropping system

P6.1 (annual to perennial) 2 rice season to coconut intercop with sugarcane



Description

Changing from rice to coconut could be an option in an area with water shortages and increased levels of salinity in soil and water. When rice cannot survive in extreme heat conditions, coconut can be one of the options.

GHG emissions were estimated using the EXACT tool under a scenario of shifting flooded rice to > 10 years of perennial trees.

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Social IRR	Social NPV	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	%	US$	Before	After
Value	$3,733	49	4	4223	49	1,382	2 rice season	Coconut with sugarcane intercopping in the first 3 years

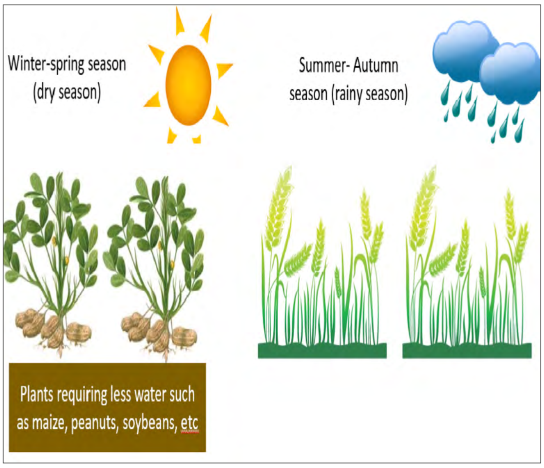
Aggregate analysis CBA tool summary	Total area of rice	Current adoption rate	Adoption rate	Aggregated NPV	Period
	81 ha	0%	47%	$398.892	10 years

Source: Financial analysis AMD Tra Vinh.

Discussion

Unlike the rice-shrimp system, coconut is used to replace the whole two seasons of rice when the level of drought and salinity sharply increase so that rice no longer can grow. This practise requires a higher initial investment than the rice-shrimp system, but it is more stable as coconut was reported to be easy to grow by farmers. However, farmers need to have guaranteed market access for their coconut products.

P6.2- 2 rice season to 1 rice – 1 upland/veggie (peanuts)



Description

Changing 2-rice seasons to 1-rice-1-vegetable/upland crop is often seen in areas facing water shortage problems. Winter-spring rice is usually faced with drought, leading to extreme yield loss. With increased temperature, the rice crop will not survive and farmers tend to plant other crops that do not demand much water, such as peanut, soybean or maize. In this case, peanut was used to replace rice in the winter-spring season.

GHG emissions from changing rice-rice to rice-upland/vegetables are estimated to reduce by 0.9 t CO_2/ha in 2015 (Trinh et al 2013).

CBA analysis

CBA tool summary Farm (1 ha) results	Net present value (NPV)	Internal rate of return (IRR)	Pay back Period	Social IRR	Social NPV	Initial investment	Scenario in the analysis (9 years)	
Unit	US$	%	years	US$	%	US$	Before	After
Value	6,466	Na	Na	6,498	Na	-1,252	2 rice season	Rice-peanuts
Aggregate analysis CBA tool summary	Total area of rice	Current adoption rate	Adoption rate	Aggregated NPV		Period		
	81	8%	44%	$317,663		10 years		

Source: Financial analysis AMD Tra Vinh.

Discussion

Similar to the rice-shrimp system, peanuts or any kind of upland crops or vegetables are used to replace winter-spring rice when temperatures increase and lead to lack of water for cultivation. This practise requires less initial investment than 2-rice seasons, but the benefits generated are also less than in the 2-rice system. The benefits of rice-vegetable/upland crop is only higher than the rice-rice system when family labour is taken into account. However, family labour is often excluded based on farmers' perspective. If winter-spring rice cannot survive, farmers can either replace it with another suitable crop or leave the land barren during the winter-spring season. Hence, the adoption rate is predicted to be 97% after 10 years and USD 620 545 would be gained for 81 ha of rice.

5. Cluster analysis results. Adoption probability of CSA practises based on characteristics of target population

5.1. Cluster description

As explained in the methodology section, rice producers were clustered and compared with rice CSA practises. Descriptive information on all rice producers is presented in table 16.

Table 16. Rice households characteristics in five research communes

Characteristic (n = 103 households)	Unit	Value
Age of household head (Mean, Std.Dev)	Number	52, 10
Male-headed households	%	89
Female-headed household	%	10
Household size (Mean, Std.Dev)	Number	4.2, 1.3
Household labor (Mean, Std. Dev)	Number	3, 1.1
Education level* (Mean, Std.Dev)	Number	2.5, 0.8
Income per capita (Mean, Std.Dev)	$US	1037, 1093
Average farm size (Mean, Std.Dev)	ha	1, 0.7
Average rice farm size (Mean, Std.Dev)	ha	0.7, 0.5
Households with formal credit	%	54

Notes: * Education levels: 1 = no school, 2 = elementary school, 3 = secondary school, 4 = high school, 5 = above high school; 1 USD = 22,500 VND.

Source: Households survey (2015).

Male-headed households account for 80% of the total sample. There was a wide distribution in income per capita. Half of the households had access to credit.

From hierarchical clustering using Ward's method, there were three groups of population classified in table 17.

Group 1 consisted of 16% of total rice producers, with a higher income level, lower labour density and a better education level compared to the other two. Households in group 1 preferred practises, which were less labour intensive. The characteristics of the group allowed them to make high investment and use a high level of complex practises, but only 10% of the income of this group came from rice. Group 2 (18% of the total sample) had a medium-sized income, education level and labour density compared to group 1 and group 2. Group 2 only had 18% income dependency on rice, so they might not have invested as much money in rice practises as other groups. Households in group 3 accounted for 66% of the total sample, had a low income level (48% under poverty line), were lower educated, had a higher income proportion dependent on rice, had higher labour density and 34% of them had drought problems. With these features, households in group 3 tended to prefer practises involving water management, with no or minimum investment, increasing yield and/or economic efficiency such as: alternative wetting and drying, 1 must 5 reduction, organic fertilizer, IPM and rice–vegetables/upland crop rotation.

Table 17. Characteristics of population clusters and its likelihood adoption of CSA practises

	Group 1 (Mean ± Std. Dev)	Group 2 (Mean ± Std. Dev)	Group 3 (Mean ± Std. Dev)
% of total sample	16	18	66
Average total income ($US)	15181 ± 5172	5896 ± 1158	1644 ± 885
Average per capita income ($US)	3214 ± 910	1327 ± 416	445 ± 277
Average farm size (ha)	1.5 ± 0.6	1.1 ± 1	0.8 ± 0.5
Average number of labor	3.2 ± 1.1	3 ± 1.2	2.9 ± 1.1
Labor density (person/ha)	2	2.7	3.6
Education level*	3 ± 0.7	3 ± 0.8	2.3 ± 0.8
Average rice farm size (ha)	1.1 ± 0.7	0.9 ± 0.7	0.6 ± 0.4
Proportion of income from rice (%)	10	13	46

* Notes: Education levels: 1 = no school, 2 = elementary school, 3 = secondary school, 4 = high school, 5 = above high school
1 USD = 22,500 VND

Source: Households survey (2015).

Table 18. Benefit from CSA practises versus characteristics of each group

Practises	Variables	Unit	Group 1	Group 2	Group 3
Salinity resistant rice	NPV	%	2	5.1	18.3
	NPV (average rice field)	%	3	5.6	14.6
	Initial cost (average rice field)	%	0.2	0.4	1
Organic fertilizer	NPV	%	1.4	3.5	12.5
	NPV (average rice field)	%	2	3.8	10
	Initial cost (average rice field)	%	-0.6	-1.2	-3.1
Rice-shrimp	NPV	%	2.4	6.1	21.8
	NPV (average rice field)	%	3.5	6.7	17.4
	Initial cost (average rice field)	%	8.6	16.2	42.2
Rice-coconut	NPV	%	2.5	6.3	22.7
	NPV (average rice field)	%	3.7	7	18.2
	Initial cost (average rice field)	%	13.7	25.8	67.3
Rice-peanuts	NPV	%	4.2	11	39.3
	NPV (average rice field)	%	6.4	12.1	31.5
	Initial cost (average rice field)	%	-12.4	-23.4	-60.9

Source: Households survey (2015).

We compared the three groups with CSA practises for rice, which were assessed in the above section (table 18). The practises included: salinity-resistant rice, organic fertilizer for rice, rice–shrimp, rice to coconut–sugarcane and 2-rice to rice–peanut, of which 4 practises addressed spontaneous drought and salinity problems and the use of organic fertilizer addressed the climate change problem in the longer term. The average annual net benefit and total income of each group was compared

The use of organic fertilizers and salinity-resistant rice practises seem to be feasible for all three groups, from poor to rich as they requires no or low investment and are easy to implement. However, the net benefit of organic fertilizer practise per average rice farm size accounts for a tiny proportion of total income of all three groups. Salinity-resistant rice produces a similar result. The rice–shrimp and rice converting to coconut and sugarcane system, require a big initial investment, equivalent to 42% and 67%, respectively of the total income of group 3, but it does not bring equivalent benefits for the group (only around 20%). Thus, in extreme climatic conditions for rice, households in group 3 might consider these practises if they have financial support. Groups 1 and 2 had no problems adopting these practises, as they did not represent a large proportion of their total income. However, given that their income dependency on rice was minimal (at around 12%), they might not be interested in rice–shrimp and rice conversion to coconut and sugarcane, unless they face serious damage from drought or increased salinity. The rice–peanut system seems to be the most feasible one for all three groups to scale-up in order to deal with water shortage conditions. This practise is context-specific and further research is needed on replacing crops for the region. In reality, it is not easy to find a suitable crop for replacement under drought conditions, which also ensures market output.

IV. Discussion

The farmers' cropping calendars correspond to climate variability; this highlights the weight of climate change impacts on farming system activities. The more farmers adapt to climate variability, the higher they measure the impact of climate change on their agricultural production. It also reflects farmers' willingness to change their traditional customs in order to avoid losses and generate more income. For example, in the case of Long Son and Ngu Lac, the 3rd cycle of rice was replaced by subsidiary crops (e.g. watermelon, green bean, winter melon etc.), which require less water than rice and so survive during the drought season. Not so many differences were found between men and women's perception on climate and cropping calendar, showing an equal level of understanding between them. The participation of women was assessed as being lower than men. The result of labour division reflected through the cropping calendar targets the correct group when considering scaling-up of a CSA practise. For example, women should be trained in CSA practises for vegetable and subsidiary crops such as drip irrigation or plastic mulching as their participation in crop production is considerable higher than men's.

Similar to farmers in other places, smallholder farmers in the study site preferred short-term benefit options to long-term ones, emphasizing the gap in awareness and adoption of CSA practises. The adaptation responses to climate change of most farmers were limited to temporary options that did not require initial investment, such as changing cropping system in the dry season, or early/late planting to avoid drought periods. The CSA practises with long-term effects received less attention from farmers in the study site. This can be explained by credit constraints and the risk-taking behaviour of farmers. The absence of micro-finance institutions makes formal banks or black credit the sole credit sources available to farmers in the region. With formal banks, farmers only can borrow small amounts of money, which might not be enough to invest in CSA practises, especially the practises that require high initial investments and with a long payback time. In addition, the risk-taking behaviour of farmers shapes their unwillingness to invest. The household survey showed that half of the non-borrowers reported that their worry of being in debt was the main reason they did not borrow money.

Mutual agreement on CSA practises between farmers and experts, including local policy makers highlights the importance of using a bottom-up approach, which acknowledges the opinion of farmers in shaping policy implementation. It is one of the important factors facilitating and promoting the adoption of CSA practises in the region. Farmers did not mention using many of the practises presented at the experts' workshop. This indicates the ineffectiveness of extension campaigns in the region, leading to a limited understanding of farmers of benefits of those practises.

While experts focused on different criteria to rank the CSA practises including profitability, results of cost benefit analysis of CSA practises provides more precise profitability in monetary value. It helps farmers and policy makers make a comparison more easily in order to prioritize and promote the adoption of a practise for each household type by considering the costs and benefits. For example, of the two practises for vegetables, plastic mulching seems to bring less benefit but requires less initial investment than drip irrigation. Therefore, plastic mulching could be more suitable for households with lower incomes. Furthermore, monetary value of CSA practises was estimated in community level, which gave a broader view for scaling-up.

The cluster analysis of rice farmers allows for a more in-depth and specific analysis of barriers and opportunities of adopting CSA practises, given the characteristic of households. For instance, the initial cost for the adoption of some of the CSA practises might be an important limiting factor for farmers with a low-income level and limited access to land. At the same time, low education levels might restrict the adoption of CSA with high level of complexity. Many farmers stated that they did not adopt CSA practises because of their technical complexities. Wealthier households normally had diversified livelihoods and therefore, might not be willing to adopt CSA practises with high initial investment for rice if it was not their main source of income. This information could serve to select specific CSA practises for each type of household. For instance, a community with a large percentage of household's livelihoods based on rice production, poor and with limited access to land should prioritize the organic fertilizer practise, as it does not require initial investment but will still bring about benefits and is sustainable. The rice–shrimp system, however, would be suitable for wealthier communities with increased salinity problems. For a community with a higher proportion of poor farmers, which is experiencing serious increased salinity issues, a solution for CSA adoption could be to facilitate access to credit.

V. Conclusion

Understanding local natural conditions, cultivation habits, challenges and constraints of agricultural production as well as household characteristics is a necessary step in selecting suitable CSA practises in the area. Alternative methods could be used to elicit such kind of information. We used a mixed-methods approach including participatory workshops (farmers and experts) and household surveys to gather information on agricultural production activities, climate conditions, challenges and constraints of farmers in 5 communes in Tra Vinh and Ben Tre province. The study identified soil conditions and suitable crops, climatic variability and its effect on crops, the existing solutions and potential solutions based on farmers' perceptions.

In general, men had more concerns about climate variability than women and they came up with more solutions than women. The most serious climate problem in the area was drought and as a result most practises concentrated on adaptations to cope with water shortages for cultivation. The term "climate-smart agricultural practises" is a new concept for farmers but they are undertaking alternative means to overcome their problems of crop production. Farmers had a deep understanding of the cropping calendar based on which cropping patterns were changed to fit their land conditions, weather uncertainty and price fluctuations.

Farmers reported limited market access and lines of credit; they stated that the available credit was not enough for big investments in many agricultural activities. Furthermore, the lack of information on market prices, quality of the products and pests and diseases caused losses in production.

Mutual agreement on adaptation practises were experienced between farmers and local experts, such as plastic mulching, drip irrigation, practises which reduced inputs (e.g. fertilizers, pesticides, seed, water), integrated crop management using organic manure and composting. Nevertheless, scaling-up these practises depended on markets for the products, availability of initial investment funds and local conditions, such as soil, cultivation habits and knowledge levels.

Almost all of the practises outlined in farmers' and experts' workshop were unknown and barely used, especially those requiring investment. There was a big gap between awareness and adoption of the practises. The commonly reported constraint to their adoption was high investment. Of the practises with no investment, organic fertilizer proved to be the most popular in all five communes. IPM was used more for rice and fruit production.

Findings from the economic assessment of the CSA in comparison with the cluster population suggested that groups with lower incomes and who were more dependent on rice were likely to adopt practises that required no investment, while higher income groups could adopt practises with higher investment.

Annexes

Annex 1. GCMs list

Centre(s)	model	xRes	yRes	nCols	nRows	xMin	xMax	yMin	yMax
Beijing Climate Center. China.	bcc_csm1_1	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
Beijing Climate Center. China.	bcc_csm1_1_m	1.125	1.121277	320	160	-180.563	179.4375	-89.7022	89.70216
Beijing Normal University. China.	bnu_esm	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
Canadian Centre for Climate Modelling and Analysis. Canada.	cccma_canesm2	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
National Center for Atmospheric Research. USA.	cesm1_bgc	1.25	0.942408	288	192	-180.625	179.375	-90.4712	90.4712
National Center for Atmospheric Research. USA.	cesm1_cam5	1.25	0.942408	288	192	-180.625	179.375	-90.4712	90.4712
Commonwealth Scientific and Industrial Research Organization/Bureau of Meteorology. Australia	csiro_access1_0	1.875	1.25	192	145	-180.938	179.0625	-90.625	90.625
Commonwealth Scientific and Industrial Research Organization/Bureau of Meteorology. Australia	csiro_access1_3	1.875	1.25	192	145	-180.938	179.0625	-90.625	90.625
Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence. Australia.	csiro_mk3_6_0	1.875	1.864677	192	96	-180.938	179.0625	-89.5045	89.50451
The First Institute of Oceanography, SOA. China	fio_esm	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
Geophysical Fluid Dynamics Laboratory. USA.	gfdl_cm3	2.5	2	144	90	-180	180	-90	90
Geophysical Fluid Dynamics Laboratory. USA.	gfdl_esm2g	2.5	2.01111	144	90	-180	180	-90.4999	90.49994
Geophysical Fluid Dynamics Laboratory. USA.	gfdl_esm2m	2.5	2.01111	144	90	-180	180	-90.4999	90.49994
NASA/GISS (Goddard Institute for Space Studies). USA.	giss_e2_h_cc	2.5	2	144	90	-180	180	-90	90

(continues)

(continued)

Centre(s)	model	xRes	yRes	nCols	nRows	xMin	xMax	yMin	yMax
NASA/GISS (Goddard Institute for Space Studies). USA.	giss_e2_r	2.5	2	144	90	-180	180	-90	90
NASA/GISS (Goddard Institute for Space Studies). USA.	giss_e2_r_cc	2.5	2	144	90	-180	180	-90	90
Russian Academy of Sciences, Institute of Numerical Mathematics. Russia.	inm_cm4	2	1.5	180	120	-181	179	-90	90
Institut Pierre Simon Laplace. France.	ipsl_cm5a_lr	3.75	1.894737	96	96	-181.875	178.125	-90.9474	90.94737
Institut Pierre Simon Laplace. France.	ipsl_cm5a_mr	2.5	1.267606	144	143	-181.25	178.75	-90.6338	90.6338
Institute of Atmospheric Physics, Chinese Academy of Sciences. China	lasg_fgoals_g2	2.8125	3.050847	128	60	-181.406	178.5938	-91.5254	91.52542
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	miroc_esm	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	miroc_esm_ chem	2.8125	2.789327	128	64	-181.406	178.5938	-89.2585	89.25846
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	miroc_miroc5	1.40625	1.400437	256	128	-180.703	179.2969	-89.628	89.62795
Met Office Hadley Centre. United Kindom	mohc_ hadgem2_cc	1.875	1.25	192	145	-180.938	179.0625	-90.625	90.625
Met Office Hadley Centre. United Kindom	mohc_ hadgem2_es	1.875	1.25	192	145	-180.938	179.0625	-90.625	90.625
Max Planck Institute for Meteorology . Germany.	mpi_esm_lr	1.875	1.864677	192	96	-180.938	179.0625	-89.5045	89.50451
Meteorological Research Institute. Japan.	mri_cgcm3	1.125	1.121277	320	160	-180.563	179.4375	-89.7022	89.70216
National Center for Atmospheric Research. USA.	ncar_ccsm4	1.25	0.942408	288	192	-180.625	179.375	-90.4712	90.4712

(continues)

(continues)

Centre(s)	model	xRes	yRes	nCols	nRows	xMin	xMax	yMin	yMax
Bjerknes Centre for Climate Research, Norwegian Meteorological Institute. Norway	ncc_noresm1_m	2.5	1.894737	144	96	-181.25	178.75	-90.9474	90.94737
National Institute of Meteorological Research, Korea Meteorological Administration. South Korea.	nimr_hadgem2_ao	1.875	1.25	192	145	-180.938	179.0625	-90.625	90.625

Annex 2. Sea-level rise studies

Possible sea-level rise by 2100 based on the academic literature:

- Model projections of future global mean sea-level change, based on temperature change projections, reveal an increase in temperature between 8–88 cm from 1990 to 2100 (IPCC 2001). This information was discussed in a paper assessing the impacts of climate change vulnerability of Rice Prod in SE Asia (Wassmann et al 2009).
- "A pragmatic choice is to consider 48 cm (or in round terms, 50 cm) as a lower range for the twenty-first century sea-level rise in a beyond 4ºC world" (Nicholls et al 2011).
- A rise of 0.8 m is possible (Pfeffer et al 2008, in Nicholls et al 2011).
- Rohling et al (2008) concluded that plausible global sea-level rise scenarios were 0.55–1.10 m in 2100 and 1.5–3.5 m in 2200.
- Maximum global rise of 2.5 m is according to Lowe et al (2010) very unlikely to occur during next 100 years.
- "The global distribution of effective sea-level rise (ESLR) under the contemporary baseline condition (figure 4) shows estimates ranging from 0.5 to 12.5 mm yr−1 with a mean value of 3.9 mm yr−1 and a median of 4.0 mm yr−1." (Ericson et al 2006)
- Church and White (2006) discovered a significant acceleration of sea-level rise in the twentieth century and estimated a sea-level rise from 2.0 to 3.4 m between 1990 and 2100.

Annex 3. Universal Soil Loss Equation (USLE) and intermediate results

A = R * K * LS * C * P

Where: **A:** annual soil loss rate (ton/ha/yr)

R: rainfall factor (MJ.mm/ha.yr)

K: soil erodibility factor (ton.ha.h/MJ.ha.mm)

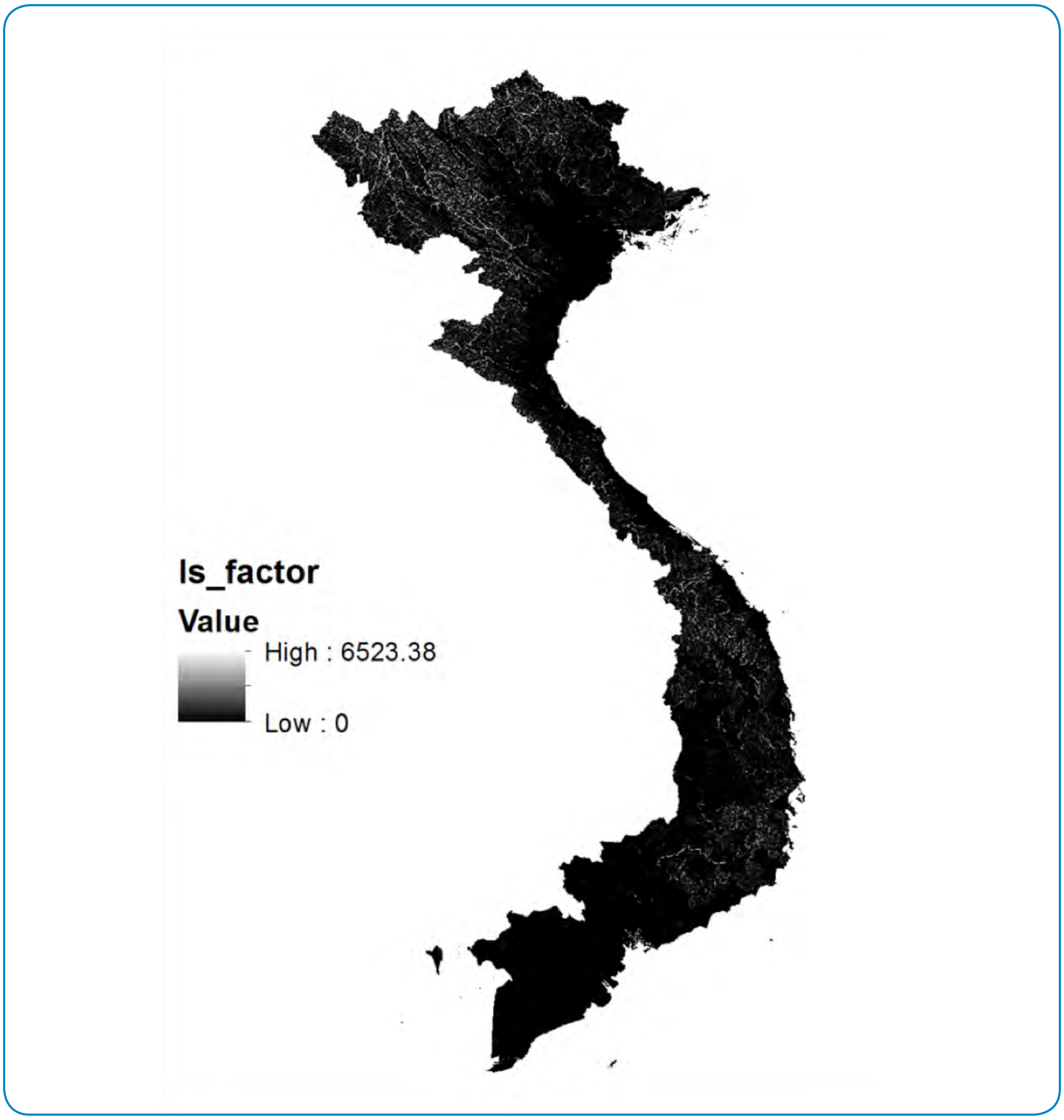
LS: slope steepness and slope length factor (dimensionless)

C: cover factor (dimensionless)

P: conservation practises (dimensionless)

Slope length-steepness (LS)

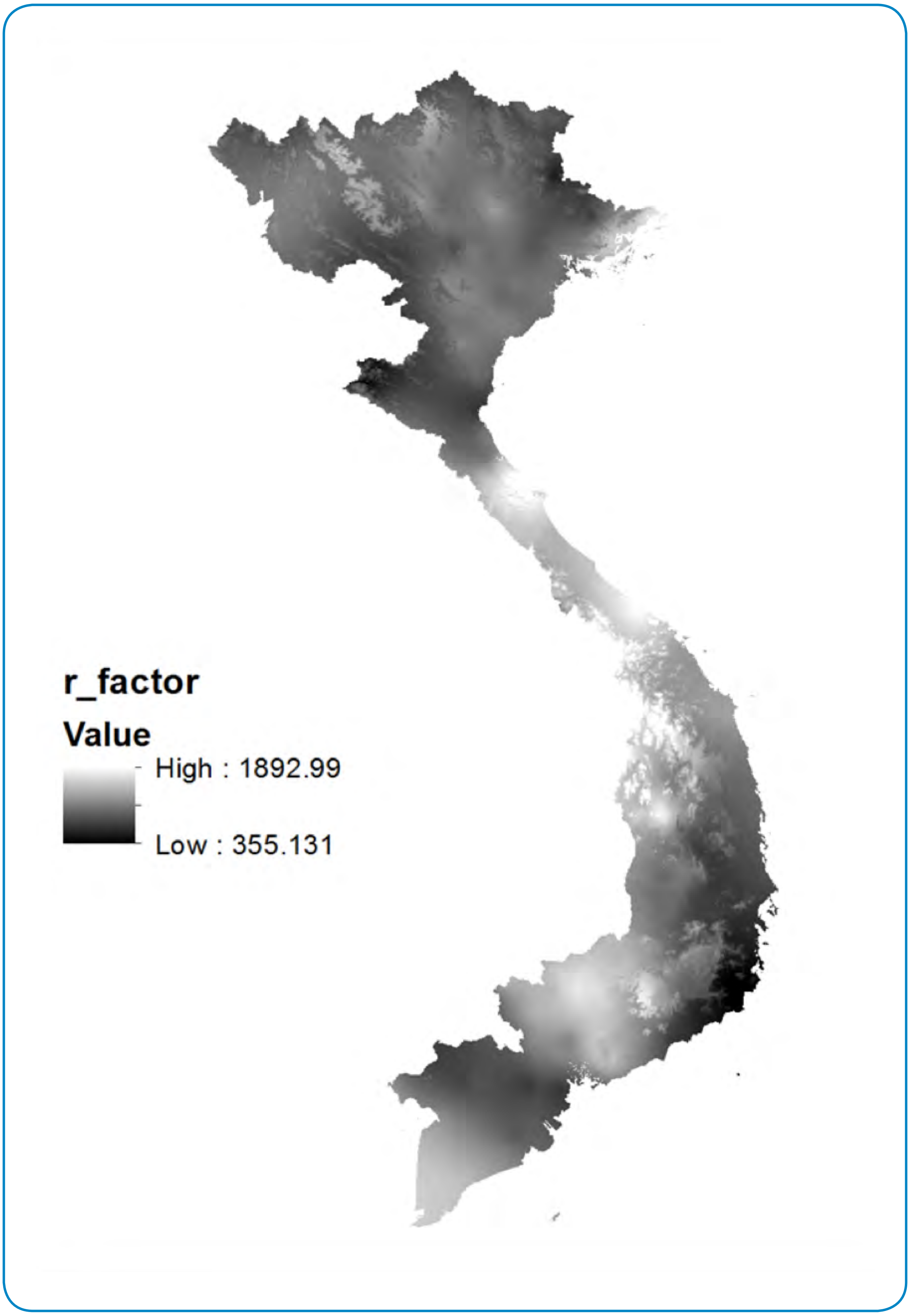
LS = Power("flow accumulation" * cell size /22.1,0.5) * Power(sin (slope * 0.01745) /0.09,1.3) * 1.5



Rainfall and runoff factor (R)

"Rfactor" = 0.548257 * Rainfall - 59.9

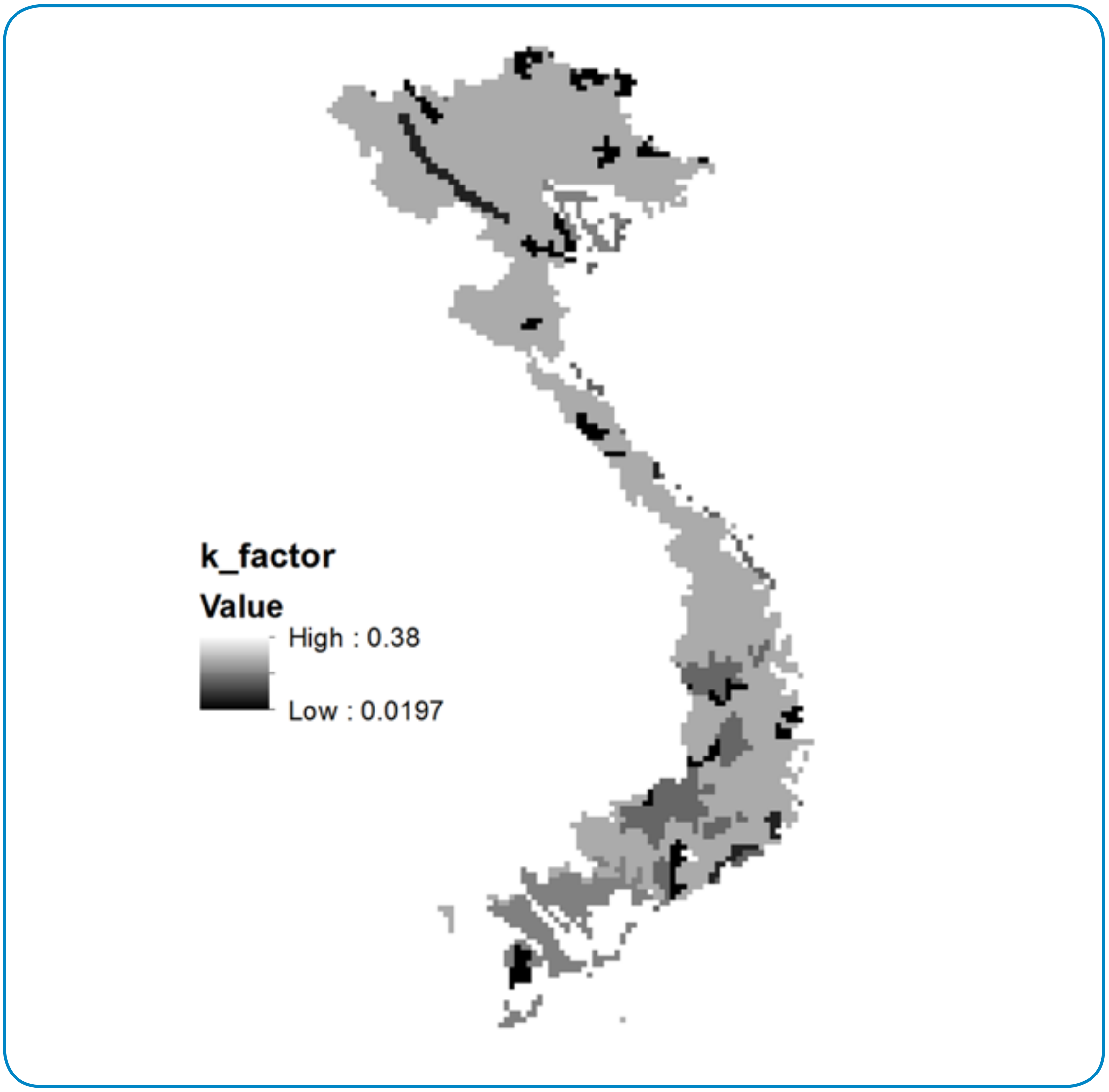
Using Bio_12 from WorldClim as rainfall and Bien Le Van (2014).



Soil erodibility (K)

Value	Soil	K	Source
1	Acrisols	0.28	Nguyen, 2009
4	Arenosols	0.194	Ashiagbor et al., 2013
8	Cambisols	0.05	Ranzi et al., 2012
9	Fluvisols	0.23	Nguyen, 2009
10	Ferralsols	0.2	Nguyen, 2009
11	Gleysols	0.38	Nguyen, 2009
14	Histosols	0.0197	da Silva et al., 2011
16	Leptosols	0.028	Ranzi et al., 2012
17	Luvisols	0.12	Nguyen, 2009
28	Vertisols	0.0374	da Silva et al., 2011

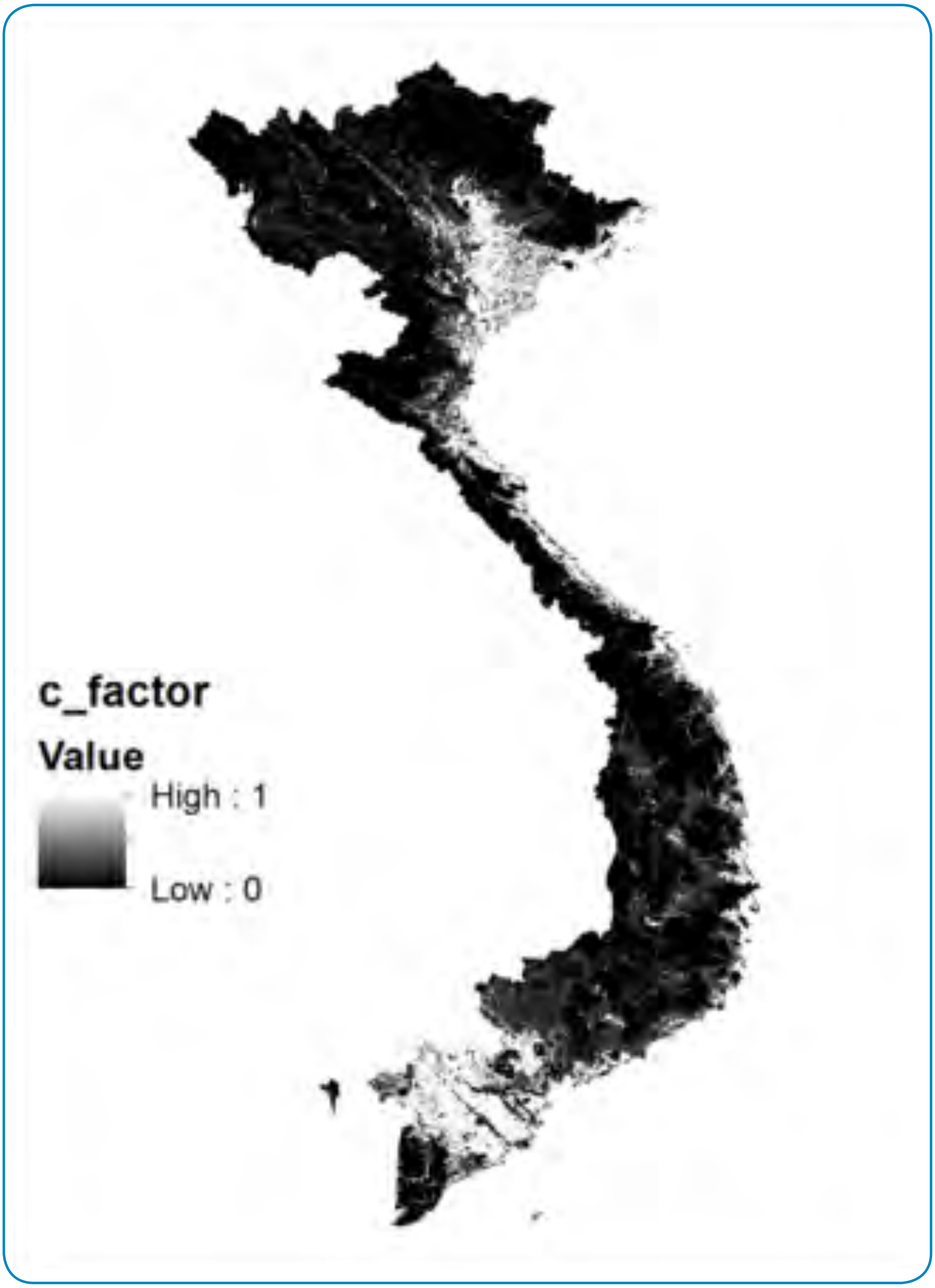
The source for soil map and classification is GAEZ v3.0 (IIASA/FAO, 2012).



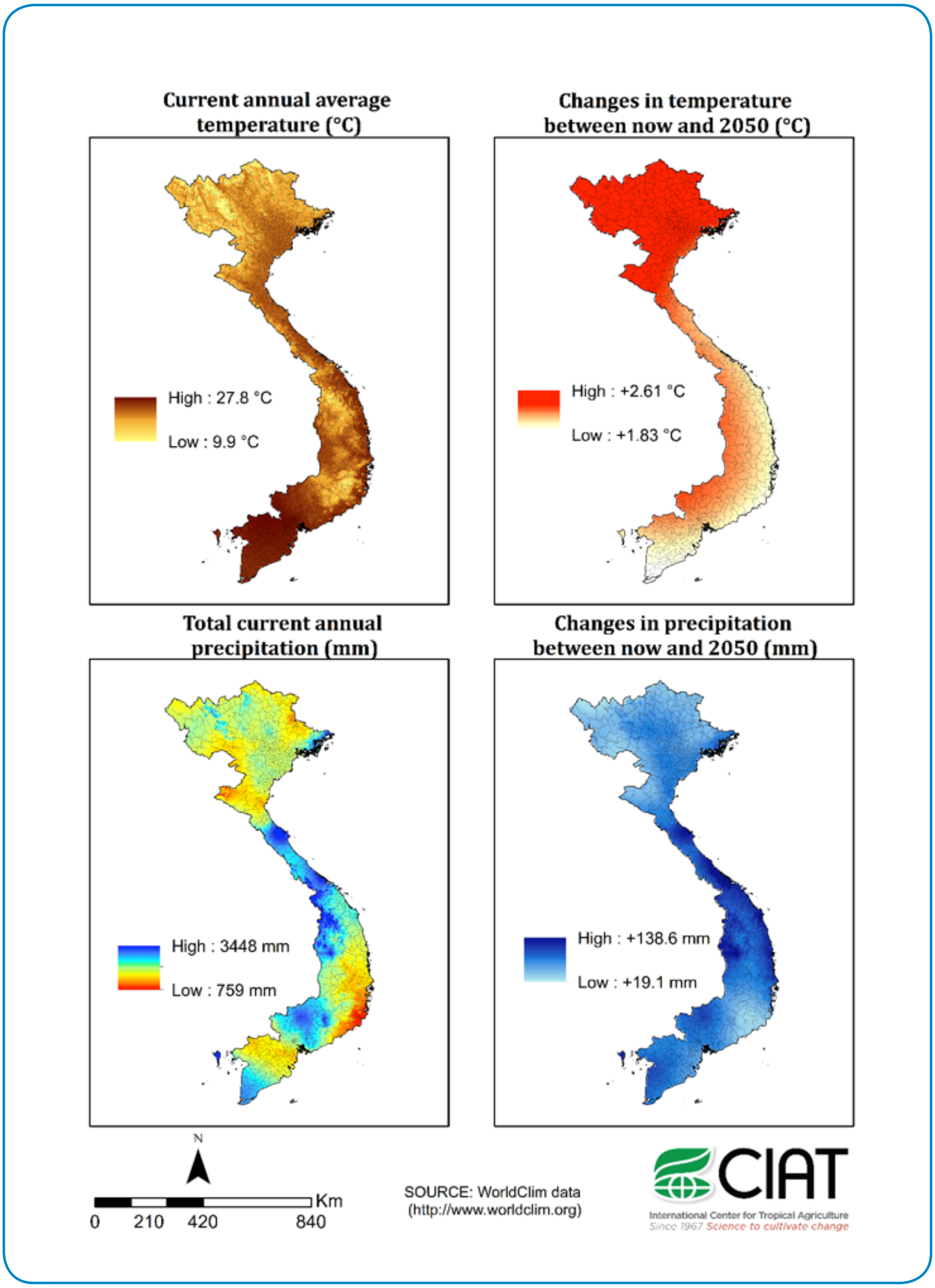
Cover Factor (C)

C factor from Morgan (2005) and Land cover from USGS (Broxton, 2014). For croplands, rice was selected as it is the most grown crop in Vietnam.

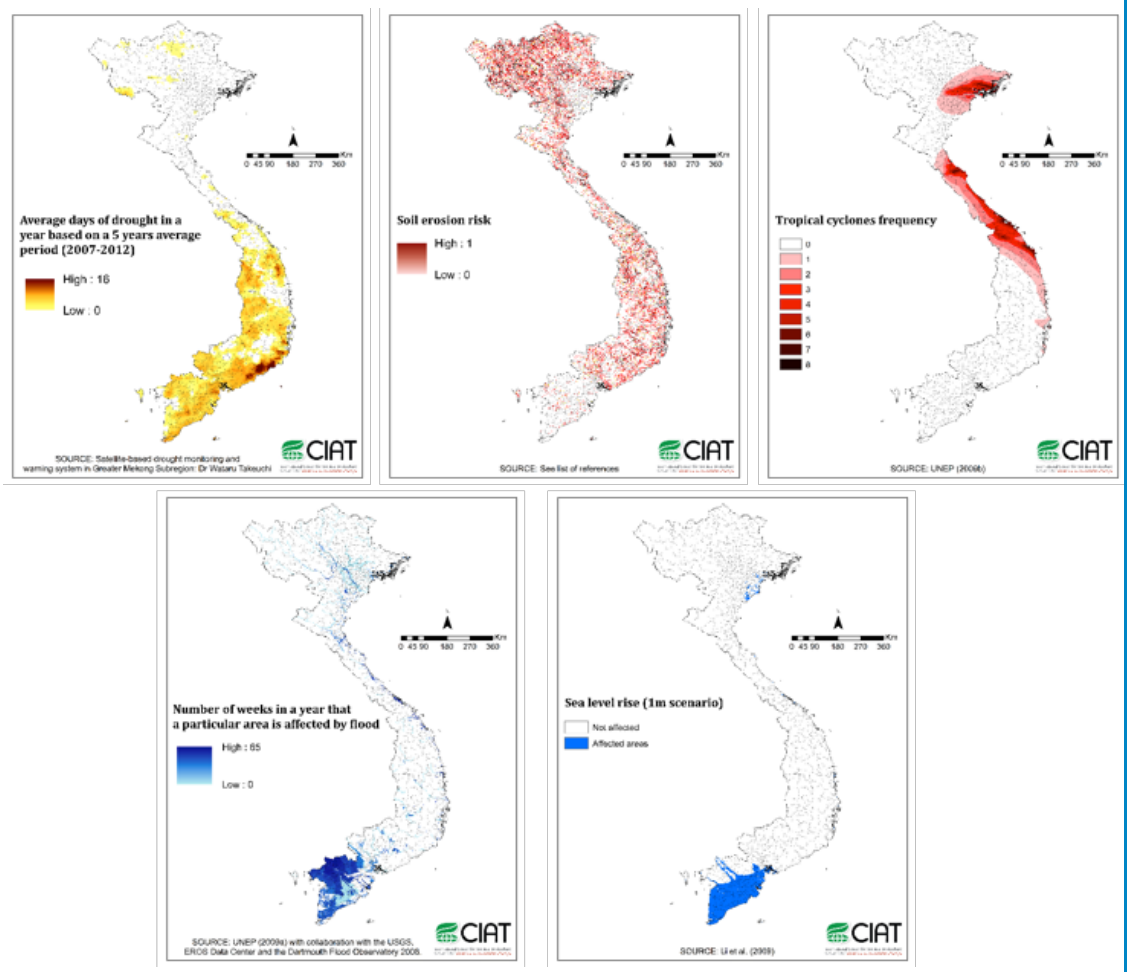
Value	Legend	C Factor
0	Water	0
2	Evergreen Broadleaf Forest	0.001
3	Deciduous Needle leaf Forest	0.001
4	Deciduous Broadleaf Forest	0.001
5	Mixed Forests	0.001
6	Closed Shrublands	0.001
7	Open Shrublands	0.01
8	Woody Savannas	0.01
9	Savannas	0.01
10	Grasslands	0.1
11	Permanent Wetland	0
12	Croplands*	0.2
13	Urban and Built-Up	0
14	Cropland/Natural Vegetation Mosaic	0.05
16	Barren or Sparsely Vegetated	1


c_factor
Value
High : 1
Low : 0

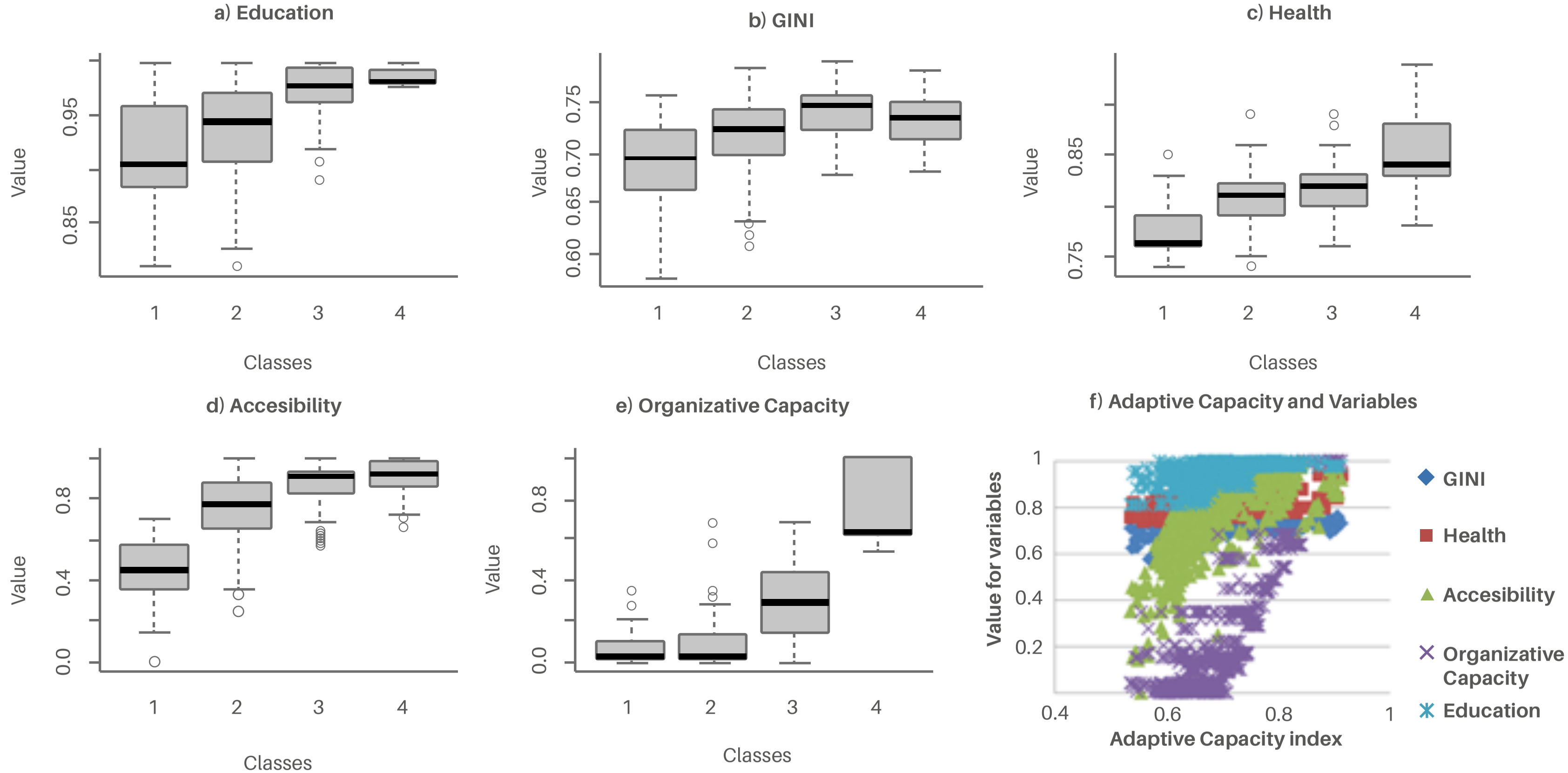
Annex 4. Changes in temperature and precipitation for 2050´s



Annex 5. Biophysical indicators

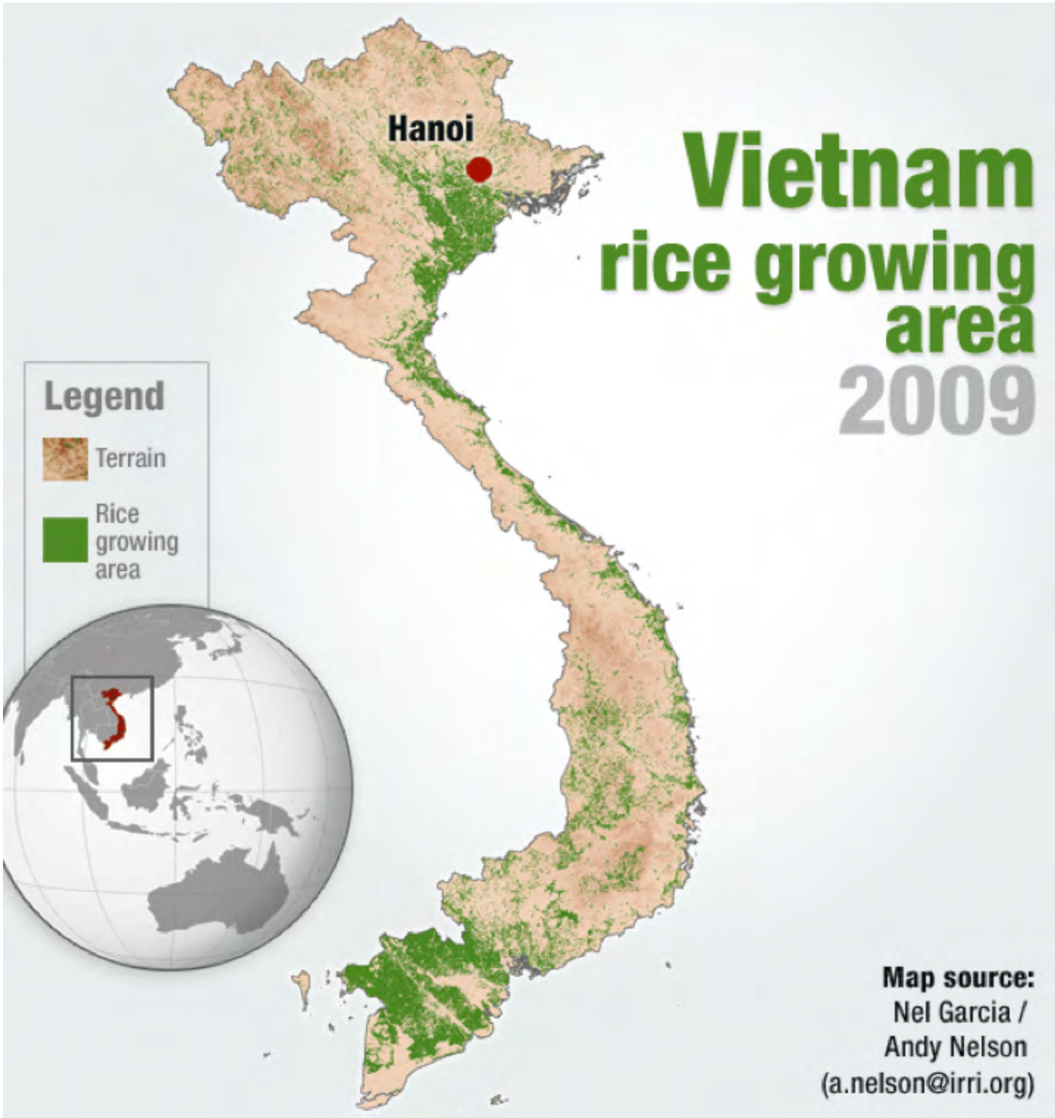


Annex 6. Adaptive capacity and indicators

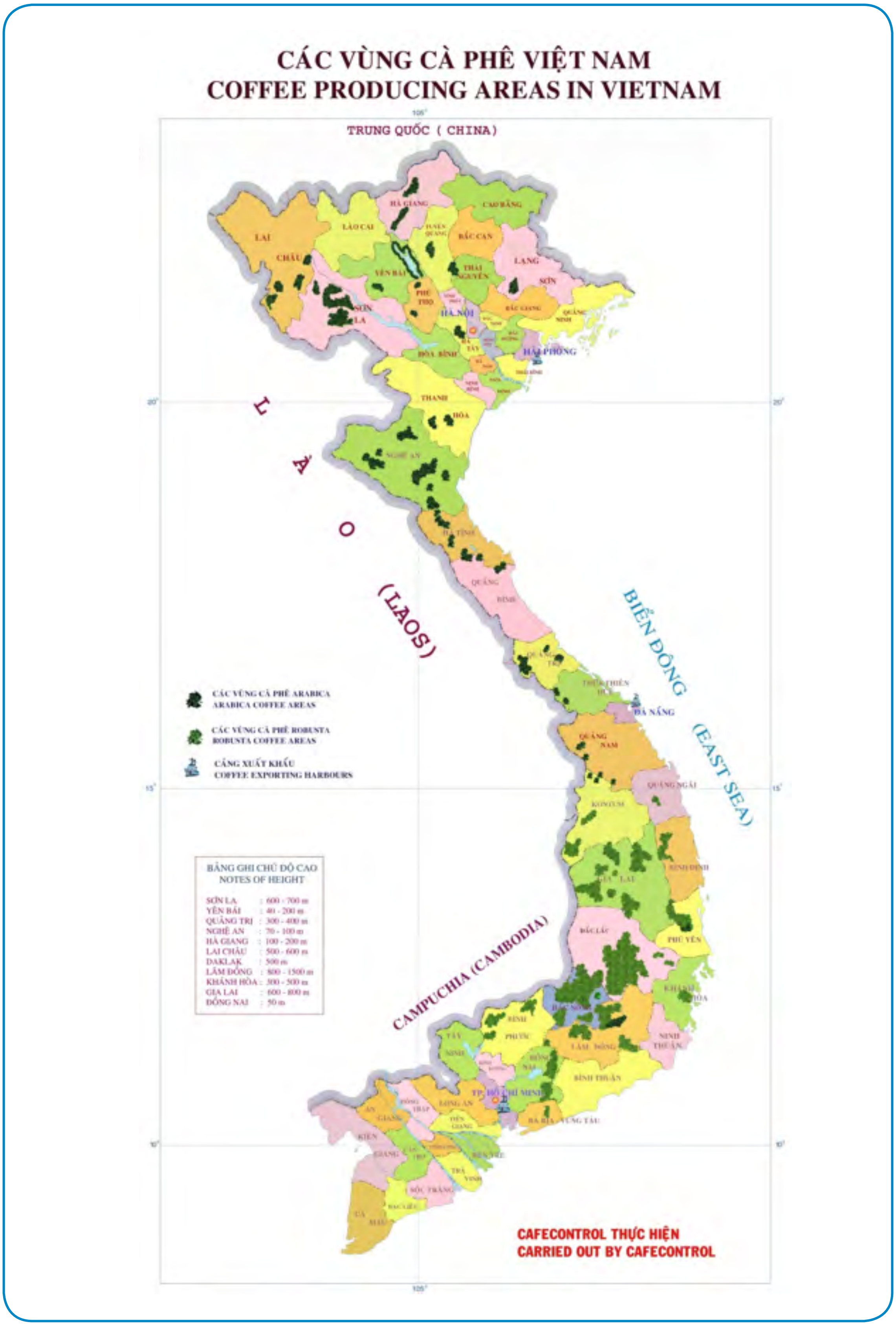


I_gini	I_health	I_access	I_organi	I_educa	I_mean
Min. :0.5760	Min. :0.7400	Min. :0.0000038	Min. :0.00000	Min. :0.8102	Min. :0.5358
1st Qu.:0.7082	1st Qu.:0.7900	1st Qu.:0.6815825	1st Qu.:0.02022	1st Qu.:0.9190	1st Qu.:0.6487
Median :0.7309	Median :0.8100	Median :0.8261822	Median :0.13210	Median :0.9681	Median :0.6840
Mean :0.7254	Mean :0.8116	Mean :0.7818146	Mean :0.20602	Mean :0.9474	Mean :0.6944
3rd Qu.:0.7508	3rd Qu.:0.8300	3rd Qu.:0.9127275	3rd Qu.:0.34870	3rd Qu.:0.9805	3rd Qu.:0.7310
Max. :1.0000	Max. :0.9400	Max. :0.9978063	Max. :1.00000	Max. :0.9989	Max. :0.9146

Annex 7. IRRI map for Vietnam rice-growing areas



Annex 8. CAFECONTROL map for Vietnam Robusta-growing areas



http://cafecontrol.com.vn/

References

Ashiagbor G, Forkuo E, Laari P, Aabeyir R. 2013. Modeling soil erosion using RUSLE and GIS tools. International Journal of Remote Sensing & Geoscience 2(4):7–17.

[AVA] Agricultura Vulnerabilidad y Adaptacion. 2013. Análisis interinstitucional y multisectorial de vulnerabilidad y adaptación al cambio climático para el sector agrícola de la cuenca alta del río Cauca. Impactando políticas de adaptación. Reporte técnico. Alianza Clima y Desarrollo.

Bien Le V, Minh Truong P, An Tran T, Raghavan B. 2014. An open source GIS approach for soil erosion modeling in Danang City, Vietnam. International symposium on geoinformatics for spatial infrastructure development in earth and allied sciences. http://goo.gl/lgQu6Z (Accessed 1 November 2015).

Broxton PD, Zeng X, Sulla-Menashe D, Troch PA. 2014. A global land cover climatology using MODIS data. Journal of Applied Meteorology and Climatology 53:1593–1605.

Carletto C. 1999. Constructing samples for characterizing household food security and for monitoring and evaluating food security interventions: theoretical concerns and practical guidelines. Technical Guide No 8. IFPRI. Washington D.C.

[CIAT] International Center for Tropical Agriculture. 2014. Sustainable management of cassava in Asia. Cali, Colombia.

Collet L, Corner C, Lefroy R. 2012. Vulnerability assessment in Vietnam. Decision and Policy Analysis Research Area. International Center for Tropical Agriculture (CIAT).

Coumou D, Rahmstorf S. 2012. A decade of weather extremes. Nature Climate Change 2:491–496

Creswell JW, Plano Clark VL, Gutmann M, Hanson W. 2003. Advanced mixed methods research designs. In: A Tashakkori, C Teddlie, eds. Handbook of mixed methods in social and behavioral research. Thousand Oaks, CA: Sage. p. 209–240.

Da Silva AM, Alcarde-Alvares C, Hitomi Watanabe C. 2011. Natural potential for erosion for Brazilian territory. In: D Godone, ed. Soil erosion studies. Intech. http://goo.gl/cAa2Zn (Accessed 31 October 2015).

Ericson, J, P., Vorosmarty, J, C., Dingman, L, S., Ward, G, L., Meybeck, M. (2006) "Effective sea-level rise and deltas: causes of change and human dimension implications." Global and Planetary Change50.1 (2006): 63-82.

[FAO] Food and Agriculture Organization of the United Nations. 2000. The Ecocrop database. http://ecocrop.fao.org/ecocrop/srv/en/home (Accessed 31 October 2015).

[FAO] 2010 Ranking the Food Security Crops. Chapter 2. FAO. http://bit.ly/2hjT4On [Accessed 11 October 2016]

[FAO] Food and Agriculture Organization of the United Nations. 2013. Climate-smart agriculture sourcebook. http://www.fao.org/docrep/018/i3325e/i3325e.pdf (Accessed 30 June 2016).

[FAOSTAT] Statistics Division of [FAO]. 2015. FAOSTAT database. Rome: FAOSTAT. http://faostat3.fao.org/download/Q/QV/E (Accessed 31 October 2015).

Fritzsche K, Schneiderbauer S, Bubeck P, Kienberger S, Buth M, Zebisch M, Kahlenborn M. 2014. The vulnerability sourcebook: concepts and guidelines for standardised vulnerability assessments. Bonn, Germany, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. http://bit.ly/2ht8JbN (Accessed 31 August 2015).

Germanwatch. 2016. Global climate risk index. Bonn, Germany. http://bit.ly/2ag8KfX (Accessed 31 August 2015).

[GSO] General Statistics Office of Vietnam. 2005a. Agriculture, forestry and fishery. Number of cooperatives in 2005 by kind of activity and by province. http://bit.ly/2gJmepO (Accessed 21 October 2015).

[GSO] General Statistics Office of Vietnam. 2005b. Press release on the 2004 household living standard survey preliminary results. http://bit.ly/2huSgEJ (Accessed 31 October 2015).

[GSO] General Statistics Office of Vietnam. 2011. The percentage of students graduating from high school by province. http://bit.ly/2huVYy2 (Accessed 31 October 2015).

[GSO] General Statistics Office of Vietnam. 2016. Gross domestic product at current prices by economic sector by year, items and economic sector. http://bit.ly/2gJnFUV (Accessed 30 April 2016).

Ha PQ et al, 2012. Report on impact evaluation, identification and implementation of adaptation options for agriculture and fisheries. Vietnam Ministry of Agricultural and Rural Development, Hanoi, Vietnam.

Harvey CA, Chacon M, Donatti CI, Garen E, Hannah L, Andrade A, ... Clement C. 2014. Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture.Conservation Letters, 7(2):77-90.

Headey DD, Ecker O. 2012. Improving the measurement of food security. IFPRI Discussion Paper No. 01225. Washington, DC: International Food Policy Research Institute.

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25(15): 1965–1978.

Hutchinson MF. 1995. Interpolating mean rainfall using thin plate smoothing splines. International Journal of Geographic Information Systems 9(4):385–403.

[IIASA/FAO] International Institute for Applied Systems Analysis/Food and Agriculture Organization of the United Nations. 2012. Global agro-ecological zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

[IPCC] 2001 Intergovernmental Panel on Climate Change. Climate Change 2001. http://bit.ly/2hCWcpJ [Accessed on 10 April 2016].

[IPCC] 2013 Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex B, Midgley BM. IPCC. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

[ISPONRE] Institute of Strategy and Policy on Natural Resources and Environment. 2009. Viet Nam assessment report on climate change. United Nations Environment Programme (UNEP) [online] www.unep.org/pdf/dtie/VTN_ASS_REP_CC.pdf (Accessed 17 June 2016).

[ISS] Institute of Social Science, University of Tokyo. 2012. Satellite-based drought monitoring and warning system in Greater Mekong Subregion (GMS). http://bit.ly/2gYdV79 (Accessed 15 October 2015).

Jarvis A, Ramírez-Villegas J, Herrera Campo BV, Navarro-Racines C. 2012. Is cassava the answer to African climate change adaptation? Tropical Plant Biology 5(1):9–29.

Jarvis A, Reuter HI, Nelson A, Guevara E. 2008. Hole-filled SRTM for the globe. Version 4, CGIAR-CSI SRTM 90m database. http://srtm.csi.cgiar.org (Accessed 10 October 2015).

Johnston R, Hoanh CT, Lacombe G, Lefroy R, Pavelic P, Fry C. 2012. Improving water use in rainfed agriculture in the Greater Mekong Subregion. Summary report. Colombo, Sri Lanka: International Water Management Institute (IWMI); Stockholm, Sweden: Swedish International Development Cooperation Agency (Sida). doi:10.5337/2012.200.

Khoury CK, Bjorkman AD, Dempewolf H, Ramírez-Villegas J, Guarino L, Jarvis A, Rieseberg LH, Struik PC. 2014. Increasing homogeneity in global food supplies and the implications for food security. Proceedings of the National Academy of Sciences of the United States of America 111(11):4001–4006.

Knutti R, Sedlacek J. 2012. Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change 3(4):369–373.

Lanjouw P, Marra, M, Nguyen C. 2013. Vietnam's evolving poverty map: patterns and implications for policy. Policy Research Working Paper Series 6355. Washington DC: World Bank.

Li X, Rowley RJ, Kostelnick JC, Braaten D, Meisel J, Hulbutta K. 2009. GIS analysis of global impacts from sea-level rise. Photogrammetric Engineering and Remote Sensing 75:807–818.

Marshall N, Marshall P, Tamelander J, Obura D, Malleret-King D, Cinner J. 2010. A framework for social adaptation to climate change sustaining tropical coastal communities and industries. Gland, Switzerland: International Union for the Conservation of Nature (IUCN).

[MONRE] Ministry of Natural Resources and Environment. 2010. Vietnam's second national communication to the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/natc/vnmnc02.pdf (Accessed 30 November 2015).

Monfreda C, Ramankutty N, Foley JA. 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types and net primary production in the year 2000. Global Biogeochemical Cycles 22, GB1022.

Morgan RPC. 2005. Soil, erosion and conservation. 3rd ed. Australia: Blackwell Publishing.

Mwongera C, Shikuku KM, Winowiecki L, Twyman J, Läderach P, Ampaire E, van Asten P, Twomlow S. 2015. Climate-smart agriculture rapid appraisal (CSA-RA): A prioritization tool for outscaling CSA: step-by-step guidelines. International Center for Tropical Agriculture (CIAT). Cali, Colombia.

Nelson A. 2008. Estimated travel time to the nearest city of 50,000 or more people in year 2000. Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra, Italy. http://bioval.jrc.ec.europa.eu/products/gam/ (Accessed 31 October 2015).

Nguyen M. 2009. Spatial modeling for soil erosion in Chay Basin in Vietnam. 7th FIG regional conference. Spatial data serving people: land governance and the environment – building the capacity. Hanoi, Vietnam, 19–22 October 2009. https://goo.gl/zkqThq (Accessed 1 October 2015).

Nicholls RJ, Hanson SE, Lowe JA, Warrick RA, Lu X, Long AJ, Carter TR. 2011. 'Constructing sea-level scenarios for impact and adaptation assessment of coastal areas: a guidance document', supporting material, Intergovernmental Panel on Climate Change task group on data and scenario support for impact and climate analysis (TGICA).

Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay JE, Mclean RF, Ragoonaden S, Woodroffe CD. 2007. 'Coastal systems and low-lying areas. Climate change 2007: impacts, adaptation and vulnerability', contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, ML Parry, OF Canziani, JP Palutikof, PJ van der Linden and CE Hanson, eds. Cambridge: Cambridge University Press. p. 315–316.

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231–259.

Ramírez-Villegas J, Jarvis A. 2010. Downscaling global circulation model outputs: the Delta method. Decision and Policy Analysis Working Paper No. 1. International Center for Tropical Agriculture (CIAT). Cali, Colombia.

Ranzi R, Thanh Hung L, Rulli M. 2012. A RUSLE approach to model suspended sediment load in the Lo River (Vietnam): effects of reservoirs and land use changes. Journal of Hydrology s422–423:17–29.

Rask KJ, Rask N. 2011. Economic development and food production–consumption balance: a growing global challenge. Food Policy 36(2):186−196.

Riahi K, Grübler A, Nakicenovic N. 2007. Scenarios of long-term socioeconomic and environmental development under climate stabilization. Technological Forecasting and Social Change 74(7):887–935.

Rohling, E.J., Grant, K., Hemleben, C.H., Siddall, M., Hoogakker, B.A.A., Bolshaw, M. and Kucera, M., (2008) High rates of sea-level rise during the last interglacial period. Nature Geoscience, 1(1), pp.38-42.Ruiter H, Kastner T, Nonhebel S. 2014. European dietary patterns and their associated land use: variation between and within countries. Food Policy 44:158−166.

Smit B, Wandel J. 2006. Adaptation, adaptive capacity and vulnerability. Environmental Change 16(3):282–292.

Steenwerth KL, Hodson AK, Bloom, AJ, Carter MR, Cattaneo A, Chartres CJ, Hatfield JL, Henry K, Hopmans JW, Horwath WR, Jenkins BM, Kebreab E, Leemans R, Lipper L, Lubell MN, Msangi S, Prabhu R, Reynolds MP, Sandoval Solis S, Sischo WM, Springborn M, Tittonell P, Vermeulen SJ, Wheeler SM, Wollenberg EK, Jarvis LS, Jackson LE. 2014. Climate-smart agriculture global research agenda: scientific basis for action. Agriculture & Food Security 3:11.

Tran DV. 2011. Climate change and its impacts on agriculture in Vietnam. Journal of International Society for Southeast Asian Agricultural Sciences 17(1):17–21.

Trinh MV, The TV, Loan BTP. 2013. Potential to mitigate GHG emissions from rice production in Vietnam. Journal of Vietnam Ministry of Agricultural and Rural Development 64–70.

[UNEP] United Nations Environment Programme. 2009. Flood frequency. Global risk data platform. http://bit.ly/2hjW9yi (Accessed 1 October 2015).

[UNEP] United Nations Environment Programme. 2014. Tropical cyclone frequency 1970–2009. UNEP/DEWA/GRID-Europe. http://preview.grid.unep.ch/ (Accessed 31 October 2015).

Vezina K, Bonn F, Cu Pham V. 2006. Agricultural land-use patterns and soil erosion vulnerability of watershed units in Vietnam's northern highlands. Landscape Ecology 21(8):1311–1325.

Wassmann R, Jagadish SVK, Sumfleth K, Pathak H, Howell G, Ismail A, Serraj R, Redona E, Singh RK, Heuer S. 2009. Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation. In Sparks, editor: Advances in Agronomy, Vol. 102, Burlington: Academic Press, pp. 91-133.

Wayne GP. 2013. The beginner's guide to representative concentration pathways. www.skepticalscience.com/docs/RCP_Guide.pdf (31 October 2015).

World Bank. 2016. Vietnam country overview. www.worldbank.org/en/country/vietnam/overview (Accessed 29 April 2016).

Zuluaga V, Labarta R, Läderach P. 2015. Climate change adaptation: the case of the coffee sector in Nicaragua, a paper presented at Agricultural and Applied Economics Association (AAEA) & Western Agricultural Economics Association (WAEA) joint annual meeting, 26–28 July, San Francisco, CA.

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