Mémoire

Agricultural vulnerability to hydrologic hazards
in the prek area of the upper Mekong Delta, Cambodia.

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Resumé

Le delta du Mekong cambodgien est une zone à forts enjeux où l'agriculture irriguée est dépendante de l'hydrologie du Mekong. Les preks, canaux d'irrigation en terre dérivant les eaux des fleuves Mekong et Bassac vers les terres basses, assurent l'alimentation en eau de nombreux périmètres irrigués entre la capitale et la frontière Vietnamienne. Le changement climatique et l'altération anthropique du régime fluvial rendent la région davantage exposée à la crue et à la sécheresse. L'objectif de l'étude retranscrite dans ce mémoire est d'évaluer la vulnérabilité de l'agriculture des preks aux aléas hydrologiques. Une campagne d'enquête a été menée auprès des agriculteurs et des acteurs de la zone, dont les données ont servi de base à la réalisation d'un diagnostic agraire. L'impact des aléas sur les systèmes de production a par la suite été estimé à partir de données d'enquête combinées à un travail de modélisation. Finalement, une analyse de la capacité d'adaptation des systèmes de production permet de conclure quant à leur niveau de vulnérabilité. Le monde agricole de la région des preks apparait très diversifié, donnant lieu à des niveaux de robustesse variables selon les systèmes de production. Les systèmes les moins vulnérables sont ceux misant sur la diversité de revenus et de systèmes de culture. Les systèmes privilégiant la monoculture ou dont le revenu annuel est exclusivement dépendant de l'agriculture sont moins robustes.

Mots clés : Agriculture; Irrigation; Vulnérabilité; Risque agricole; Inondation; Sécheresse; Delta du Mekong; Preks.

Abstract

The Cambodian Mekong Delta is a high-stake area where irrigated agriculture is dependent on the hydrology of the Mekong river. The preks, earthen irrigation canals diverting the waters of the Mekong and Bassac rivers towards the lowlands, ensure the water supply of many irrigation schemes between the capital and the Vietnamese border. Climate change and anthropogenic alteration of the river regime make the region more exposed to flood and drought. The objective of the study transcribed in this thesis is to assess the vulnerability of prek agriculture to hydrological hazards. A survey campaign was carried out among farmers and stakeholders in the area, the data from which served as the basis for an agrarian diagnosis. The impact of the hazards on production systems was then estimated based on survey data combined with modelling work. Finally, an analysis of the adaptive capacity of production systems made it possible to conclude on their vulnerability level. The agricultural world in the preks region appears to be very diversified, resulting in varying levels of robustness depending on the production systems. The least vulnerable systems are those that rely on the diversity of income and cropping systems. Systems that favour monoculture or whose annual income is exclusively dependent on agriculture are less robust.

Keywords: Agriculture; Irrigation; Vulnerability; Agricultural risk; Flooding; Drought; Mekong Delta; Preks.

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Mes premiers remerciements vont à Christina, encadrante brillante et plus que disponible, colocataire géniale. Je te souhaite de terminer ton doctorat avec brio et le succès dans tes futurs projets.

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Merci à ma famille et à Anna, pour tout.

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Foreword

This MSc internship was carried out as part of a dual academic parcours made of the Ingénieur Agronome course of the Institut National d'Etudes Supérieures Agronomiques de Montpellier SupAgro as well as the Master's degree in Water, Water and Agriculture co-accredited by AgroParisTech, Montpellier SupAgro and the University of Montpellier. This work is part of a research programme of the joint research unit G-eau (Water management, stakeholders, uses). The COSTEA project (2020-2022) aims to understand the socio-hydrological dynamics of the "preks region", a specific area of Kandal province in the Cambodian upper Mekong Delta. The research project is funded by the French Development Agency (AFD) and relies on local partnerships with the Royal University of Agriculture (RUA), the Institute of Technology of Cambodia (ITC) and the Irrigation Service Center (ISC). The PhD programme "Understanding Delta Hydrology from an Integrated Perspective - Hydrological Modelling of the Mekong Delta, Cambodia" prepared by Christina Orieschnig, as well as this related internship, are part of this framework. The COVID-19 pandemic that shook the planet in 2020 did not spare the course of this internship, whose field operations were abruptly interrupted not even halfway.

Glossary

Agrarian system	Agro-economic concept defined as « *the theoretical expression of a historically constituted and geographically localized type of agriculture, consisting of a characteristic cultivated ecosystem and a defined productive social system, the latter making it possible to sustainably exploit the fertility of the corresponding cultivated ecosystem* ». (Translated from French, Mazoyer et Roudard, 1997).
Boeung	Khmer term for lowlands within the prek system.
Chamkar	Khmer term for uplands within the prek system.
Cropping system	Agronomic concept for a system approach at plot level, based on the characteristics of the crop rotation, the varieties grown and the technical itineraries practiced.
Evapotranspiration	Agrometeorological variable representing the quantity of water (reported per unit of time) that passes from the soil into the air in the vapour state due to the combined effect of plant transpiration and direct evaporation from the soil.
Prek	Khmer term for earthen canals connecting the river (Mekong or Bassac) to lowlands.
Production system	Group of farms that may be represented by the same socio-economic and agronomic model.
Riel	Currency in Cambodia. In this thesis, the exchange rate considered is 1 usd = 4000 riel.
Transition area	Intermediary area between lowlands and uplands into the prek system.

Acronyms

ADB	Asian Development Bank
AFD	Agence Française de Développement
asl	above sea level
AusAid	Australian Agency for International Development
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWR	Crop Water Requirements
DS	Dry season
ECOLAND	Ecosystems Services and Land use Research Center
ET0	Reference evapotranspiration
ETa	Actual evapotranspiration
ETc	Crop evapotranspiration
EVI	Enhanced Vegetation Index
EWS	Early wet season
FAO	Food and Agriculture Organisation
IPCC	Intergovernmental Panel on Climate Change
IRD	French National Research Institute for Sustainable Development
ITC	Institute of Technology of Cambodia
JICA	Japan International Cooperation Agency
MOWRAM	Ministry of Water Resource and Meteorology
MRC	Mekong River Commission
PUC	Prek User Committee
RUA	Royal University of Agriculture
USD	United States Dollar
WASP	Water and Agricultural Sector Project
WAT4CAM	Water Resources Management and Agro-ecological Transition for Cambodia
WS	Wet season

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Introduction

Issues, hazards, vulnerability and adaptive capacity of agricultural sector

Agriculture is facing the challenge of feeding a growing population with limited natural resources and under increasingly unpredictable climatic conditions (IPCC 2018). Deltaic plains in particular are regions of high importance because of their fertile soils, ecological richness, high habitat density and "granary" function. The Mekong watershed covers 795,000 km², as the river flows through six countries from its source in the Tibetan plateau to its delta in Vietnam (MRC, n.d.). Particularly sensitive to climatic and hydrological hazards and anthropogenic pressures, the Mekong Delta is vulnerable and threatened (Cosslett and Cosslett, 2018). Climate change associated with the anthropization of the basin (hydroelectric dams and soil artificialization) are at the origin of remarkable variations in the hydrological regime of the Mekong (e.g. Hetch et al, 2019 and Yang et al 2019). As a result, the inter-annual variability of the monsoon regime specific to the Mekong Delta has increased (MRC data stations). On the other hand, modelling carried out for the Water for a Healthy Country Flagship project within the framework of the assessment of the impact of climate change on water resources in the Mekong River Basin in 2008 predicts an increase in rainfall volumes during the wet season and a decrease during the dry season in the delta region (Eastham et al, 2008). Thus, various studies and models show an intensification of climatic hazards such as flooding and drought.

In Cambodia, flooding is far from being a new phenomenon, and agriculture has historically adapted to its seasonality (Deligne, 2013). From an agro-economic point of view, it is an event whose effects may be both positive (fertility renewal, recession agriculture) and negative (agricultural damage). The irregularity of the phenomenon and the inter-annual variability of its intensity and temporality can increase its harmful potential (Keskinen, 2006). Mekong River Commission simulations predict an increase of between 7% and 13% of the total flooded area in Cambodia by 2060, depending on climate scenarios (MRC, 2019).

. Drought has also been recognised as major natural hazard in Cambodia (World Bank, 2006). The concept of drought has been differentiated into three categories according to The National Drought Mitigation Centre (NDMC), USA: meteorological, agricultural and hydrological. The US Geological Survey added a fourth separate class, socio-economic drought, more related to the consequences of water scarcity for a population. From an agro-economic point of view, meteorological and hydrological droughts are responsible for agricultural drought trough a soil moisture deficit and an inadequacy between crop water requirements and the available resource. In the case of irrigated agriculture, crop needs can be partially or totally met by irrigation water supply with economic and environmental consequences.

In this context of high stakes and variations in the occurrence of hazards, the question of the vulnerability of the agricultural sector arises. The widely used concept of vulnerability is defined as the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy et al, 2001). The vulnerability assessment of a system is based on three parameters: exposure, sensitivity and adaptive capacity (Doch et al, 2015). The term exposure refers to the way in which the system is subject to environmental hazards, the characteristics of which are their intensity, frequency and duration. Sensitivity represents the degree to which the system is modified or affected by the disturbance. Finally, adaptive capacity is the ability of the system to evolve in order to respond and accommodate to hazards. The higher the exposure and sensitivity and the lower the adaptive capacity, the greater the vulnerability of the system. Some authors prefer to use « robustness », the antonym of « vulnerability », to evade its negative and fatalistic connotations (Anderies et al, 2004).

The vulnerability assessment of a system is therefore inextricably linked to a spatial scale, in this case a study area in Kandal province which comprises ten irrigation schemes subdivided into hydro-agricultural units (preks). Agricultural holdings within the area are gathered into production systems reflecting their main common characteristics (Cochet, 2011). The definition of these systems makes it possible to carry out a vulnerability study based on the agronomic (technical) and socio-economic components of the area. Attempting to assess the vulnerability of an agrarian system to climatic hazards ultimately leads to the following questions being asked:

- **What are the impacts of flood and drought on agricultural production?**
- **What are the main production systems?**
- **Which stakeholders are most affected? Where?**
- **How are negative impacts amplified or mitigated by the agro-economic and social environment?**
- **What is the adaptive capacity of the production systems?**

In practical terms, the exposure to risk is represented by the variations in water availability in the area. The spatial and temporal extent of flood and drought phenomena and their variations are analysed. The sensitivity assessment of the system is based on an agrarian diagnosis and on the yield response indicator. Then, the impact of hazards is estimated by combining systems exposure and sensitivity. The adaptability of the systems is estimated through the study of the strategies deployed to limit the impacts of hydrological hazards.

I. Study of the hydro-agricultural landscape

1.1. The Cambodian Mekong Delta

1.1.1. Geography and statistics

The Cambodian Mekong Delta is a geographical and hydrological unit defined by the Cambodian Ministry of Water Resources and Meteorology as a river basin group including the provinces of Phnom Penh, Kampong Cham, Kampong Speu, Tboung Khmum, Prey Veng, Svay Rieng, Takeo and Kandal (figure 1). Between the capital Phnom Penh and the Vietnam border, the area is entered around the Mekong and Bassac rivers in its north-south axis. The vast plain is the second largest agricultural area of the country, covering 25% of the national utilised agricultural area (National Institute of Statistics, 2015). In the province of Kandal, 80% of crops are irrigated (Pacific Rim Innovation and Management Exponents, 2019).

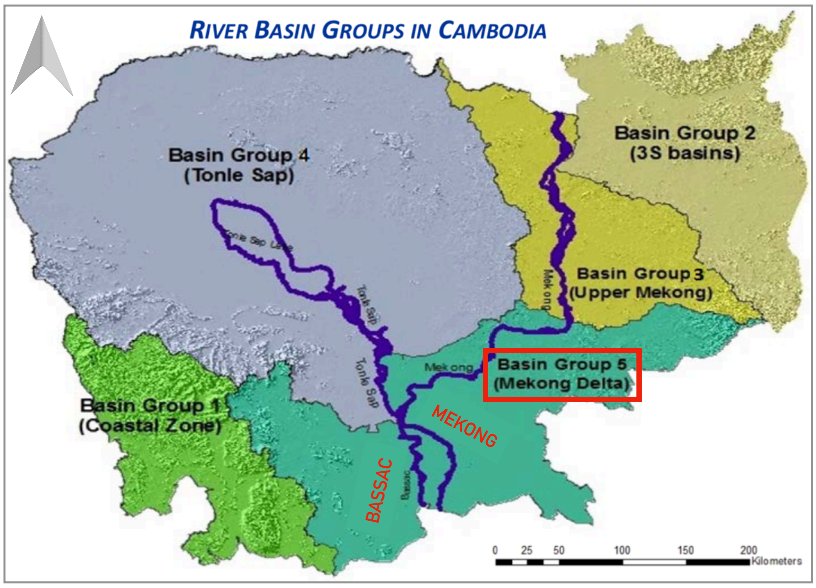


Figure 1. Cambodian river basin groups.
Source: Ministry of Water Resources and Meteorology.

1.1.2. Climate

The climate is tropical, warm and humid with a monsoon system which is marked by a wet season lasting from May to November during which monthly rainfall range between 100 et 300 mm. During the dry season (December-April), rainfall varies from 0 to 50 mm/month. On average, the annual rainfall of the Cambodian Mekong Delta is around 1200 mm/year. Rainfall is therefore highly variable in time and space, unlike temperature, the monthly averages of which lie between 22°C and 36°C, reaching their maximum in April (Pacific Rim Innovation and Management Exponents, 2019).

1.1.3. Hydrological dynamic

The state of the region's surface water resource is mainly determined by the hydrological dynamics of the Mekong river and its effluent, the Bassac. The hydrology of the delta is subject to the monsoon regime over the entire catchment area. Therefore, the flood cycle is slightly out of phase with the local rainy season: the flood phase extends from June to October and the recession phase from November to May (figure 2, MRC).

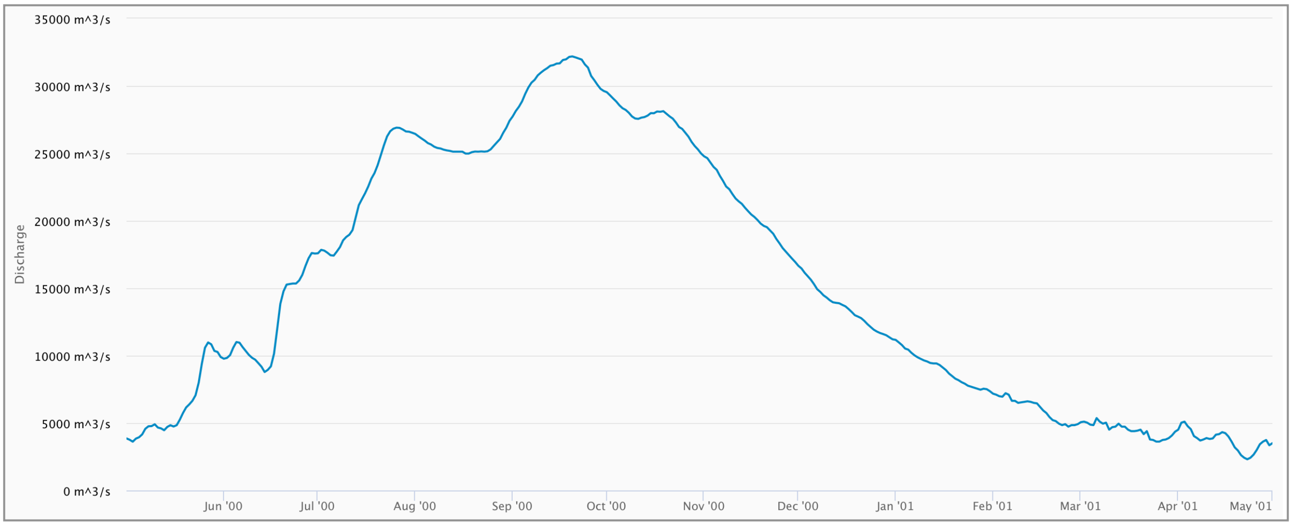


Figure 2. Mekong daily discharge, from May 2000 to May 2001, Neak Luong station. Source: MRC.

1.2. <u>The prek system</u>

1.2.1. History and development

In the detailed reports of French engineers in the early 20th century, « preks » are described as « natural flood dispatchers on the Mekong riverbank lands » (translated from French, Barthélémy, 1909). These channels, located in the Cambodian deltaic plain, debranch perpendicularly from the Mekong and Bassac rivers, breach the banks and spill over into the lowlands during flood events. During the colonial period, French engineers noticed the potential of this prek region which extends from Phnom Penh to the Vietnamese border, in the provinces of Kandal and Takeo. Two main functions were identified that should be fulfilled thanks to the preks development: colmatage and irrigation.

The colmatage function is related to the transfer of sediments during the flow of river water to the lowlands, called « boeungs ». The ambition is twofold: to « polderize » the vast swampy depressions of the boeungs and to take advantage of the nutrients contained in the sediments carried by the flood (figure 3.1). To this end, the preks « meandering and cluttered with dense vegetation » were rehabilitated to prevent silt from settling in the very bed of the canals and « frustrating of their beneficial action many hectares of land » (figure 3.2 and 3.3). The aim is to artificially provoke the formation of high-potential agricultural land, « the fertile area par excellence, the one that will give the best harvests » (translated from French, Barthelemy, 1909).

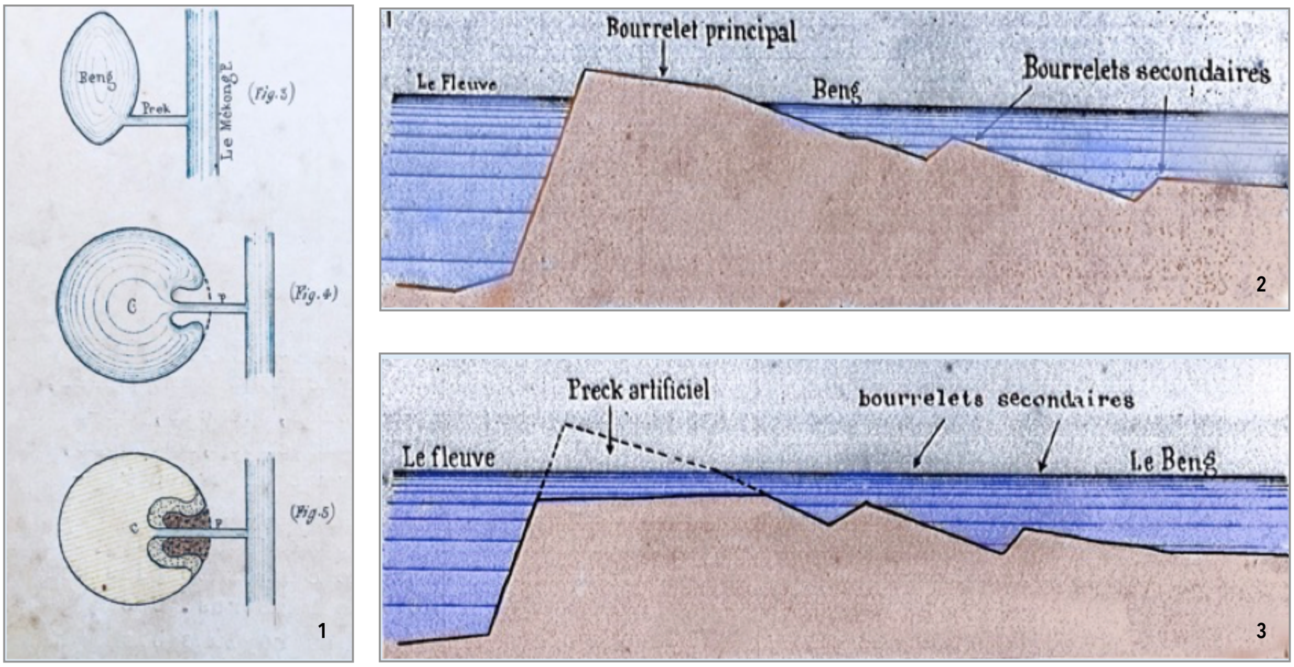


Figure 3. Hand-drawn figures from a 1912 report by colonial French engineer Lt. Barthélemy, reproduced with permission from the National Archives of Cambodia and recoloured by C. Orieschnig.

The development of irrigation is motivated by the unstable yields of rain-fed agriculture. This is how Lt. R. Barthelemy justifies it: « this regularization of the harvest through irrigation is of capital importance because the differences between a good and a bad harvest, which are a function of the abundance or scarcity of rainfall, are often considerable » (translated from French, Barthelemy, 1909).

The prek region landscape has evolved following those land and water management projects, but the functions sought at this time remain broadly similar. However, it is notable that these colonial civil work reports mention the preks operating as a network, with lowlands supplied by one canal and drained by another, depending on the season. This systemic management of the preks seems to have disappeared in favour of individual management.

In the framework of the Cambodian government's strategy for agricultural development and with the financial assistance of international donors, several prek rehabilitation programs have been implemented since 1999. The primary objective of these projects is to improve water availability for irrigation and related crop production on the chamkars and in the boeungs. Some canals have been rehabilitated as part of the Water and Agriculture Sector Project (WASP, 2014-2017) (SOFRECO, 2017), and other rehabilitations are planned in the course of the Water Resources Management and Agro-ecological Transition for Cambodia program (WAT4CAM, 2020-2024).

1.2.2. Current properties and operation

Today, preks can be defined as hydro-agricultural systems in which the following elements may be observed (figure 4):

- The **prek channel** is the structuring element of the landscape, dug in the river banks (Mekong or Bassac) and diverging perpendicularly towards the lowlands with a gentle slope. In most cases, the profile is trapezoidal and its dimensions (length, width, depth) variable. The canal is the subject of rehabilitation programmes after which it may have been dug, reshaped, widened, stripped of its vegetation and in some cases equipped with gates. The canal thus allows a connection between the river and (ephemeral) water bodies in the lower areas. The water volumes exchanged depend on the characteristics of the canal and the climatic and hydrological conditions.

- The **chamkar area** represents upland sub-system, almost never flooded. The levee (raised riverbank) formed along the rivers by sediment deposition is the initial part, surrounding the head of the prek. The area occupied by chamkar along different preks varies, representing in some cases 100% of the perimeter. The coarser sediments have accumulated at this level, resulting in sandy soils. Permanent infrastructures (roads and houses) are built on this area which is spared by the flood. The area is suitable for agricultural diversification and perennial crops, even though the soil fertility renewal isn't ensured by the flood.

- The **boeung area** represents the lowlands, regularly flooded during the wet season. At recession time, these are the most suitable lands for rice cultivation. Fine-grained deposits are left behind here by the flood every year, and soils are clayey, deep and fertile. During the flood, the area is only accessible by boat for fishing purposes. During the dry season, grazing livestock may be taken there for range pasturing.

- For the purposes of this study, the intermediary area between lowlands and uplands will be called the **transition area**. This zone has the particularity of being inundated from time to time during flood peaks, but not necessarily every year, and water depths here rarely reach above 50 centimeters. Sedimentary deposits are therefore relatively frequent there, with silty soils (silty-clay on the lower lands, silty-sand on the higher lands). The area is suitable for growing early wet season crops and the fertility may be used for growing cash crops during the dry season.

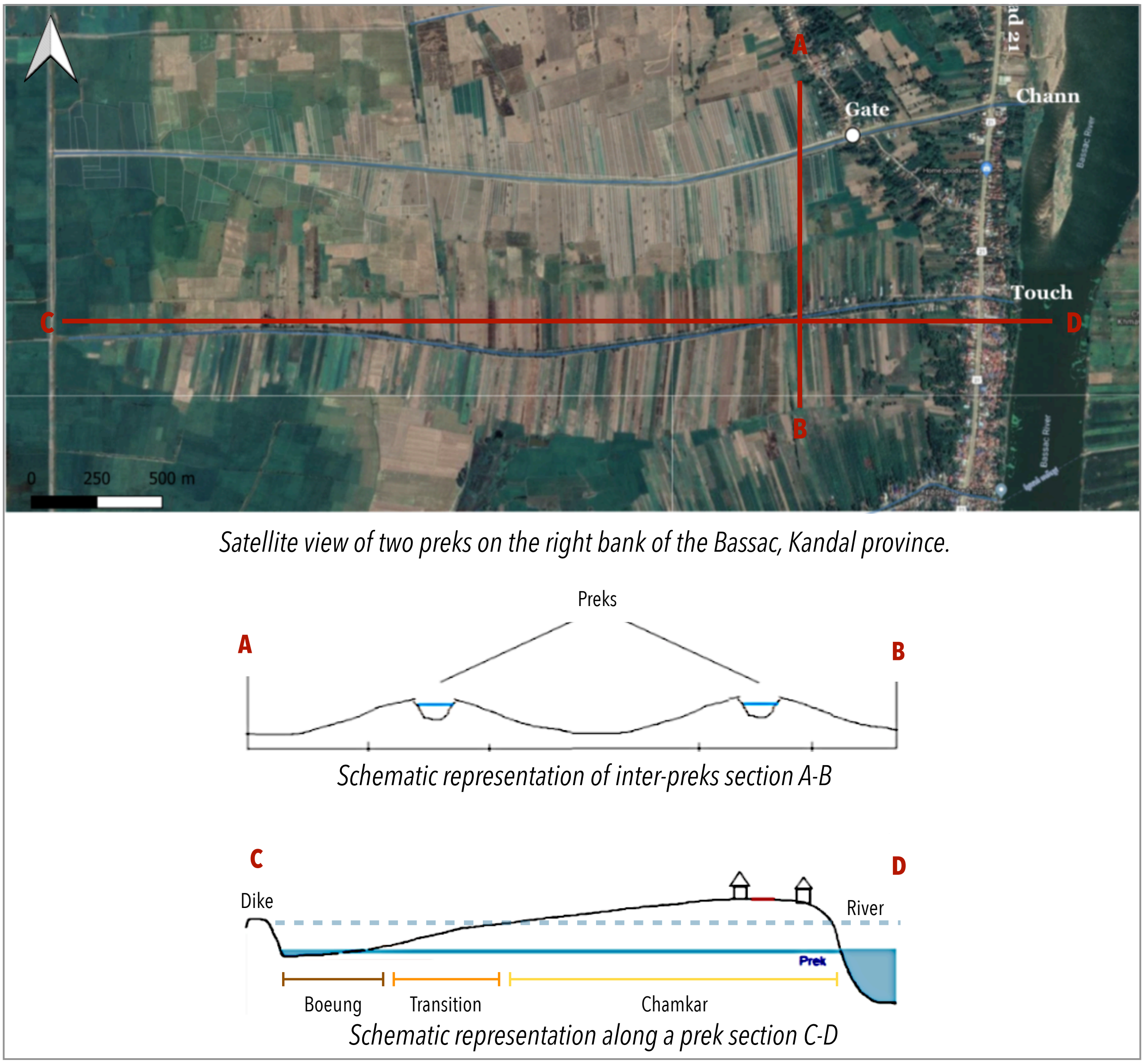


Figure 4. Schematic prek systems topography and spatial distribution , adapted from Pratx, 2017.

1.2.3. Study area definition

The study area includes ten prek systems on the right bank of the Bassac river, 60 km South of Phnom Penh in Kandal province, Kaoh Thum district (figure 5). It has the advantage of being representative of the prek region in terms of the diversity of the types of canals encountered. On the other hand, the homogeneity of the area, especially concerning the agrarian system and irrigation practices, makes it possible to analyze the whole area in a relatively pertinent way.

The area is easily accessible from the capital via National Road 21. The northernmost prek is located just south of the Koh Thom bridge (also called Chinese bridge), the last prek is 7km further south along National Road 21 (bridges 53 to 63). The eastern boundary of the area is the Bassac, its western boundary the prek Ambel (or stung Ambel). The area comprises around 4200 ha.

The zone was also chosen because of the proximity of an hydrological and meteorological station in Koh Khel, less than 20km north of the area. Bassac water levels and rainfall are measured there daily and data are freely accessible on the MRC time-series inventory website. In addition, permanent monitoring equipment (water level recorders, water electric conductivity sensors, meteorological station) is currently being installed as a basis for further studies.

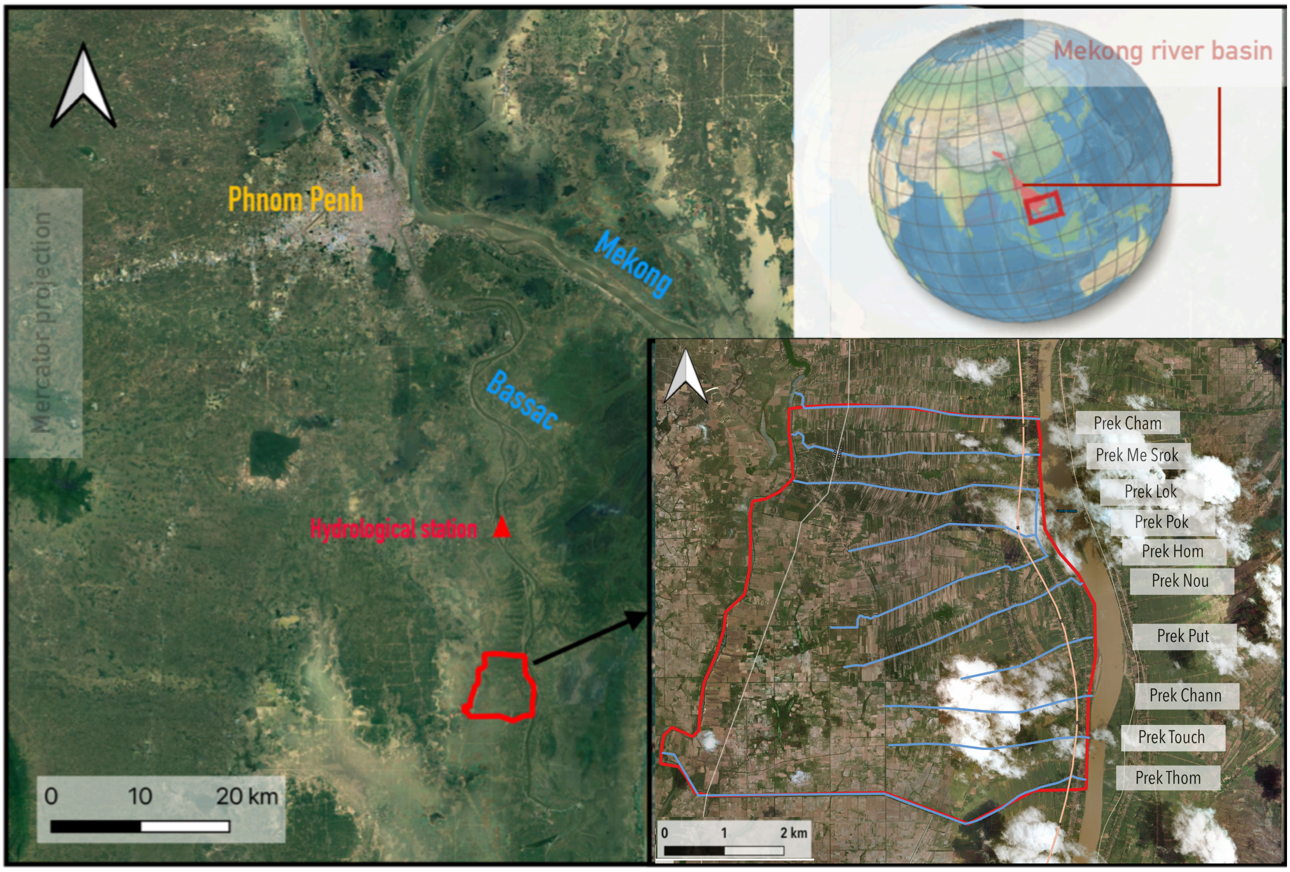


Figure 5. Study area location in the prek area of Kandal province, Koh Thum district.

1.3. Exposure of the area to hydrological hazards

1.3.1. Unequal availability of water resources in time and space

At first sight, access to water resources in the study area does not appear to be problematic. The median yearly rainfall for the period 1986-2019 is around 1180 mm (CHIRPS data) and the volumes flowing into the Bassac throughout the year are substantial. However, the exposure of the area to hydrological hazards lies in the unequal distribution in time and space of the resource. In terms of rainfall, first of all, the distinction between the wet season and the dry season is stark (figure 6). Between December and March, the median monthly rainfall is less than 30 mm/month. This period is therefore particularly subject to rainfall deficits. On the other hand, monthly rainfall volumes are regularly above 100mm/month between May and November.

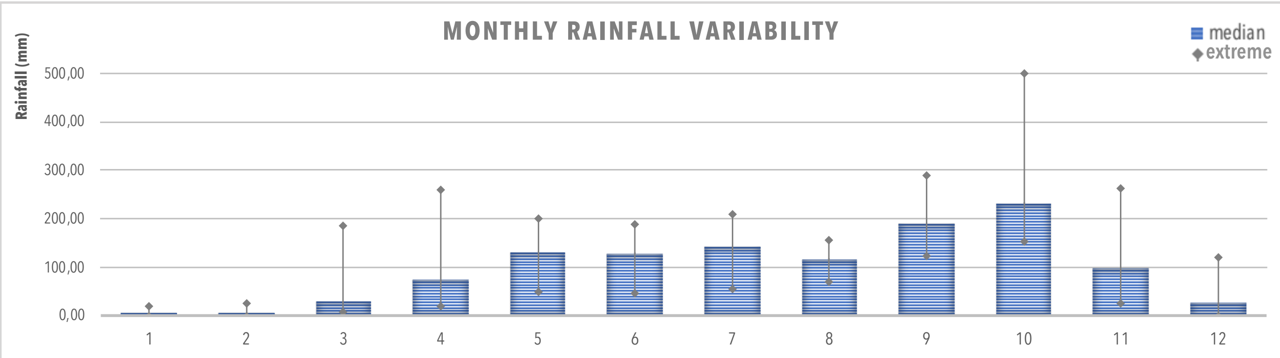


Figure 6. Annual chart of median monthly precipitation in the study area, CHIRPS data.

Moreover, the inter-seasonal variation in water availability is also reflected by the graph of Bassac water levels measured at the Koh Khel station (figure 7).

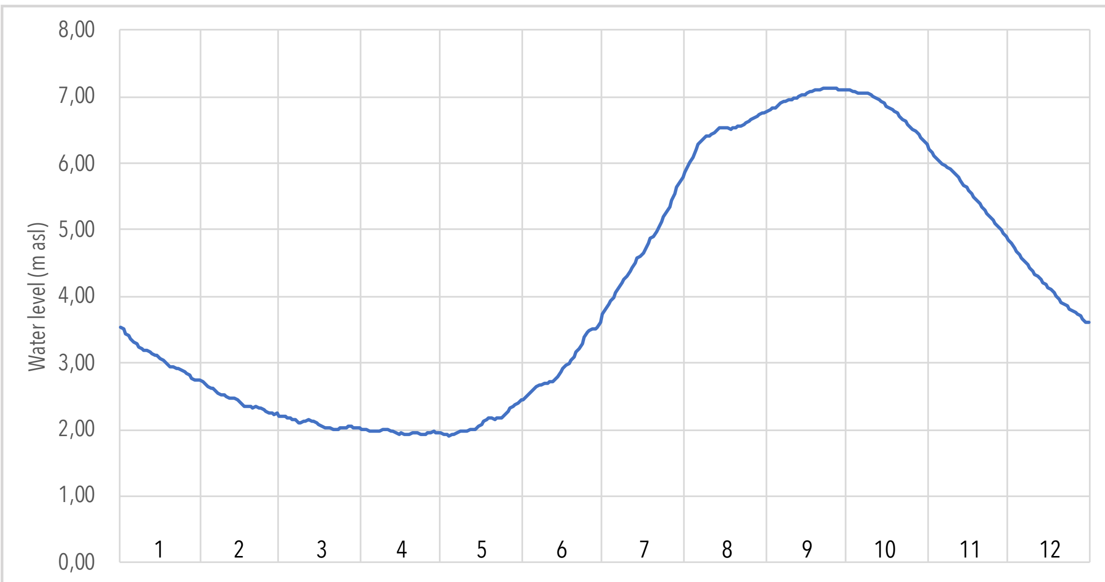


Figure 7. 1990-2019 average Bassac water levels at Koh Khel station. Source: MRC.

To this seasonality of rainfall and flooding is added an unequal spatial distribution of water resources at prek scale. As described above, the boeung areas are flooded during the wet season, the chamkar areas are not affected by the flood, and the transition areas may experience floods of varying intensity and duration depending on the year.

1.3.2. Towards an increasing irregularity of the flood

In addition to intra-annual variability, water resource availability is also variable in inter-annually, both in terms of rainfall and flood levels. The frequency analysis of the monthly rainfall deficit over the last thirty-four years shows the great variability of precipitation volumes from one year to another (Annex A). The climate modelling carried out for the Mekong Delta region predicts an increase in rainfall volumes during the rainy season and a decrease during the dry season (Eastham et al, 2008, IPCC, 2018), which would reinforce distributional inequalities in the future.

Flooding has also become increasingly irregular in recent decades. This phenomenon, reported by local farmers and village chiefs, is illustrated by the Bassac water level surveys of the last five years (figure 9) comparatively to those of the previous decade (figure 8).

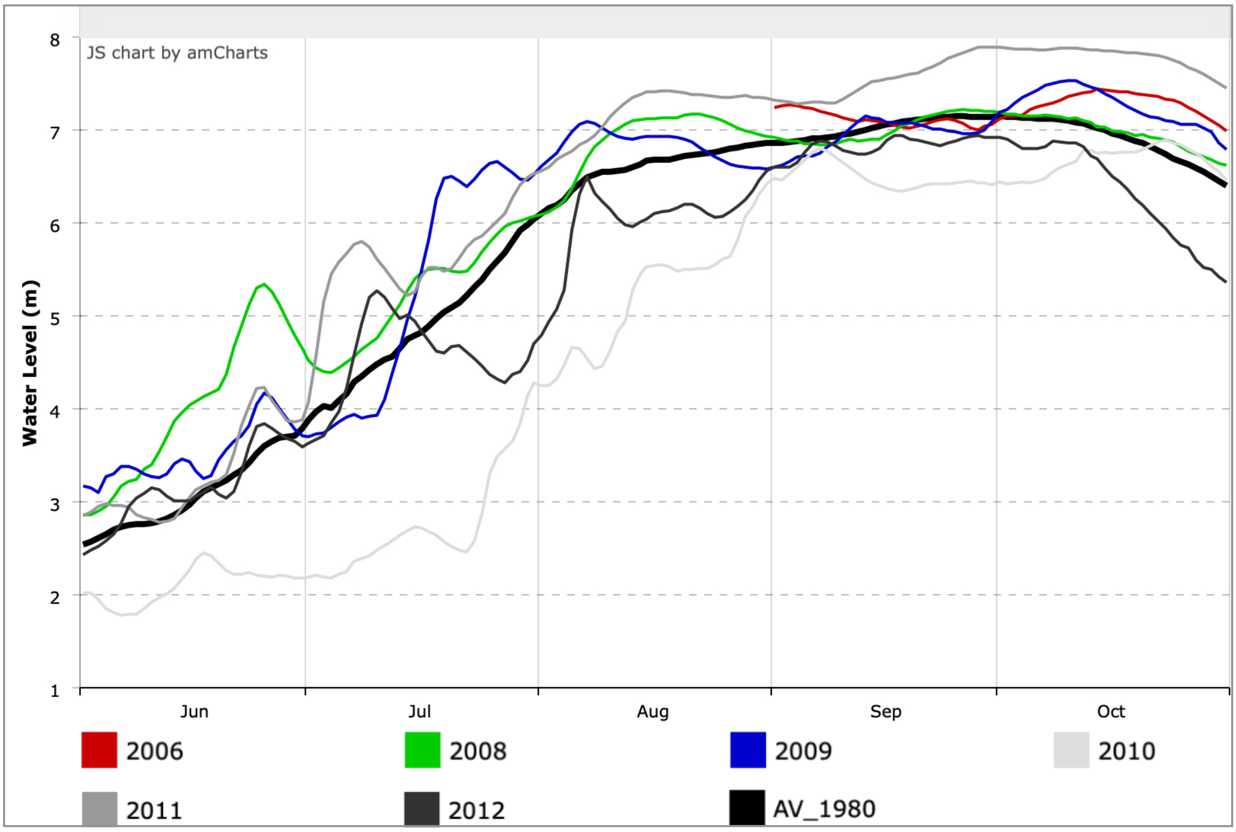


Figure 8. Inter-annual comparison of Bassac water levels at Koh Khel station during wet season, 2006-2012 time serie. Source: MRC.

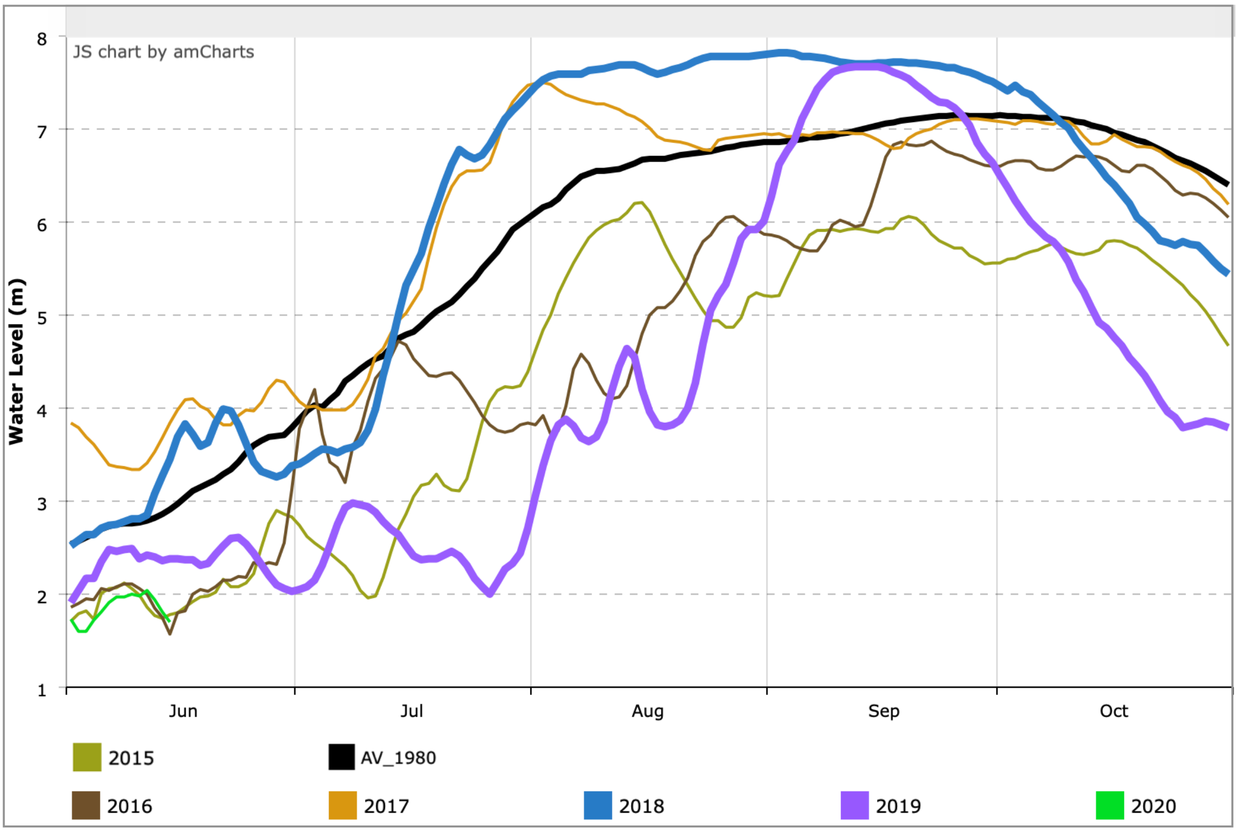


Figure 9. Inter-annual comparison of Bassac water levels at Koh Khel station during wet season, 2015-2019 time serie. Source: MRC.

The flood appears irregular both in its duration and intensity. 2018 and 2019 floods in particular are far from average and drastically from each other. In 2018, the flood was exceptional in its intensity and temporal extent. At the beginning of June, the Bassac was already 3 meters a.s.l. and the flood lasted until November. The flood peak was reached at the end of July (Bassac water level above 7 meters a.s.l.) and lasted two months. In 2019, the flood was very late and short (late August to early October). The same peak as in 2018 was reached but lasted only two weeks.

These large variations result in spatial differences in water availability. As an example, a remote sensing analysis of two preks (Chann and Touch) in the study area allows us to understand the flood variability between 2018 and 2019 (figures 10 and 11). The indicator used is the enhanced vegetation index (EVI). Flooded areas appear in red, areas covered by a thin water layer in white, bare soil in yellow/orange and vegetation in green. The exposure of the area to hazards is then understood, as flooding may occur early, thus causing damage, or late, leading to a water deficit, disrupting in all cases the cropping calendars and technical itineraries.

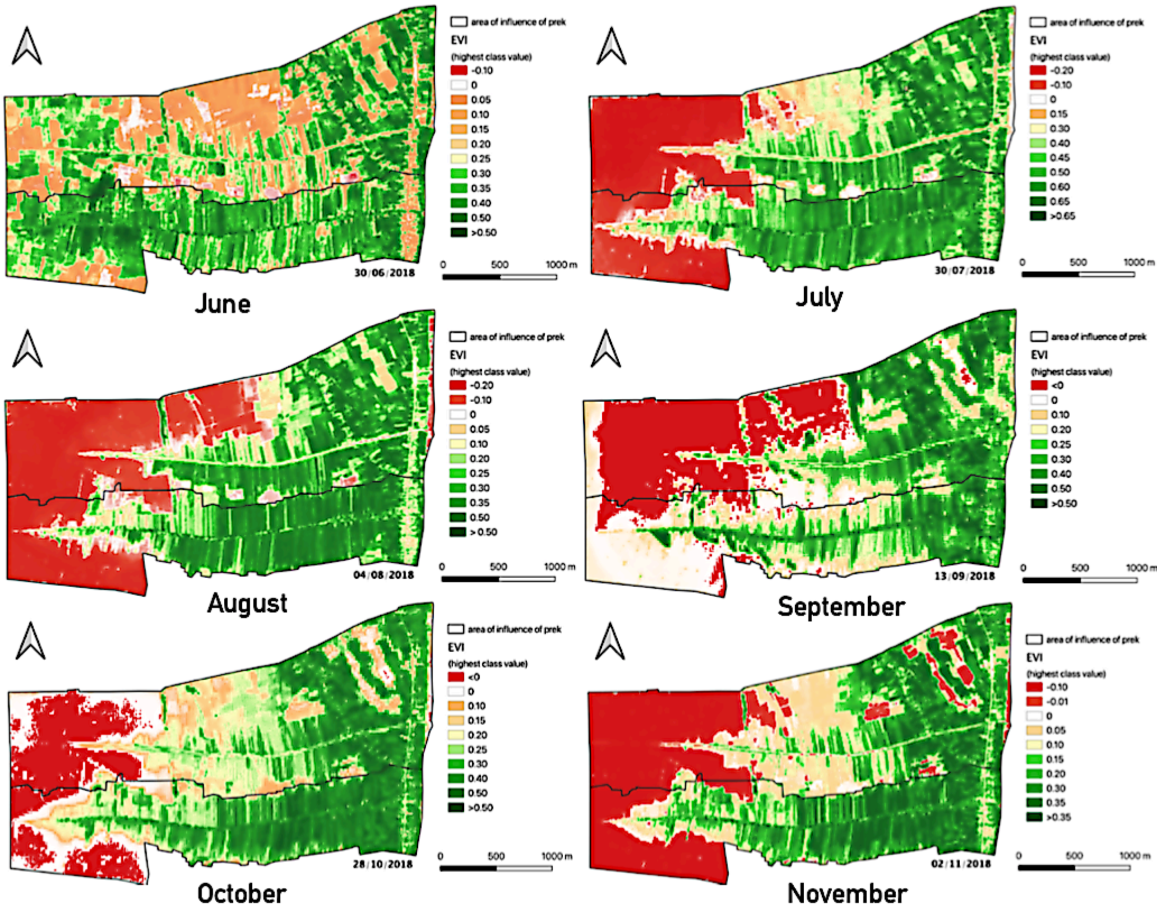


Figure 10. EVI wet season 2018, preks Chann and Touch. Source: Vandôme et al., 2020.

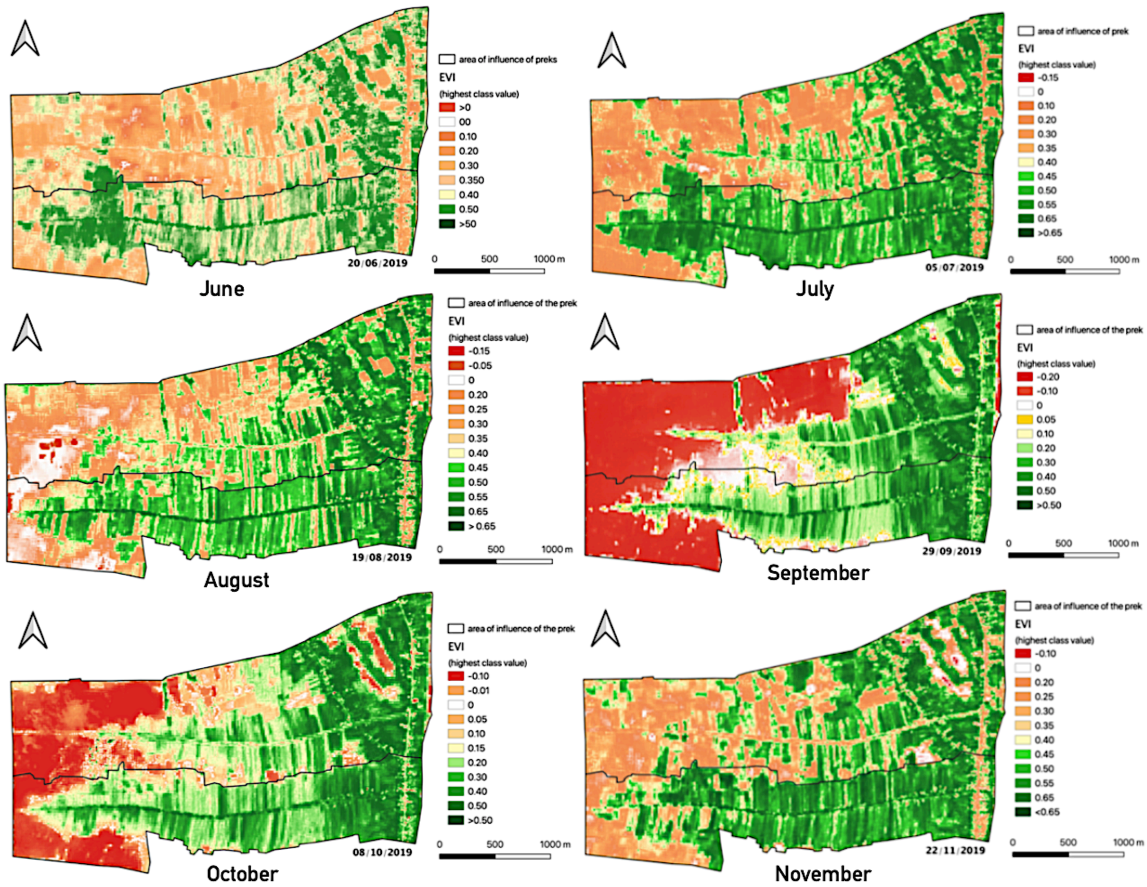


Figure 11. EVI wet season 2019, preks Chann and Touch. Source: Vandôme et al., 2020.

2. Methods

2.1. General framework

The vulnerability study has to be based on an in-depth knowledge of the study area, and a systemic representation of the area must first be established. To this end, surveys and field observations were carried out in order to describe the area using the agrarian diagnosis method. The second step is to assess the response of the described systems to hazards. In this framework, the analysis is based on two scales, firstly that of cropping systems and, secondly, that of the production systems. The drought impact will be estimated through survey results and then regarded more closely through modelling. The indicator at the cropping system level is yield reduction, the indicator at the production system level is income reduction. The estimation of the flood impact is based exclusively on survey results, but is used for the calculation of the same indicators. The production systems' adaptive capacity is then assessed qualitatively according to the following indicators: crop diversity, income diversity and flexibility (inclination to innovation and new farming practices). Finally, the vulnerability level of production systems is discussed relatively to the previous elements. The general approach is represented below (figure 12).

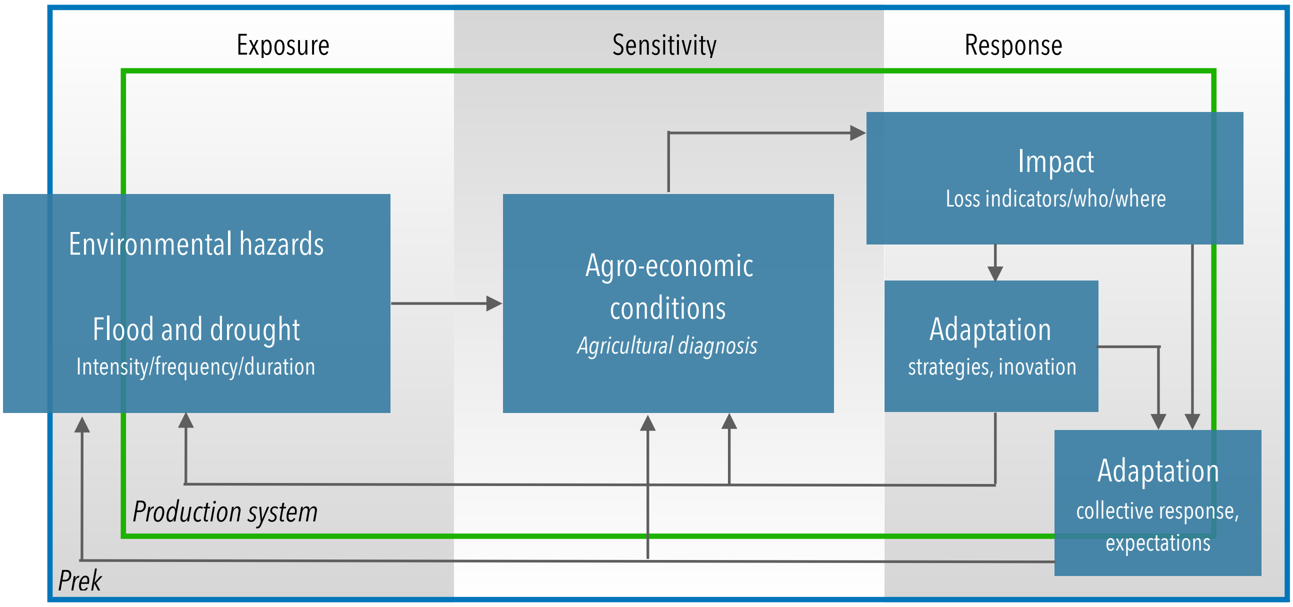


Figure 12. Schematic representation of the elements determining the system vulnerability.

2.2. Field survey

2.2.1. Interviews with farmers

The farmer survey was conducted jointly with Christina Orieschnig during three stages: from February 21st to February 22nd, from March 3rd to March 6th and from March 10th to March 13th. The questionnaires were prepared jointly with the help of J.P. Venot in order to collect the data necessary for the completion of this thesis and Christina's PhD project. The assistance of the ECOLAND team (RUA division) made it possible to carry out the field trip in the best conditions.

The interviews were conducted using a survey grid structured into different thematic parts (Annex B). The first part focuses on agro-economic information at the scale of production systems, in particular through a large-format table facilitating the overall understanding of the system (crop rotation, details of cropping systems, crop budgets, irrigation practices, etc.). Questions relating to livestock management, fishing, and the farm economic dimensions complement the table. The second part focuses on the themes of agricultural risk and farmers' adaptive capacity. The objective is to estimate the response of production systems to hazards, from a quantitative (yield losses) as well as a qualitative point of view (events explanation, farmers' feelings, willingness and strategies developed). The third part concerns the global understanding of the prek functioning and their associated ecosystem services.

The initial objective of this survey was to conduct a total of about 150 interviews in the study area, representing about 10% of the farmers active along the ten preks, i.e. an average of 15 interviews per prek. Due to the COVID pandemic, the field phase was stopped in mid-March, drastically reducing the results sample. A total of 36 farmers were interviewed in the area, with a heterogeneous distribution among the preks (Figure X). The lack of interview on prek Thom is justified by the fact that the prek was undergoing excavation during the survey. Only one interview was conducted at prek Put because it is comparatively small and highly affected by sedimentation. Furthermore, as preks Chann and Touch had already been surveyed during previous field trips (August and November 2019), they were not given priority during this first - that became only - field phase. Even tough the small sample size limits the representativeness of the survey, the results cover a total of 107 crop data grown on about 70 ha, i.e. more than 1.5% of the total study area. In addition, all cropping zones - chamkar, boeung and transition - were covered, with an emphasis on the chamkar areas where the greatest crop diversity can be found (Figure X).

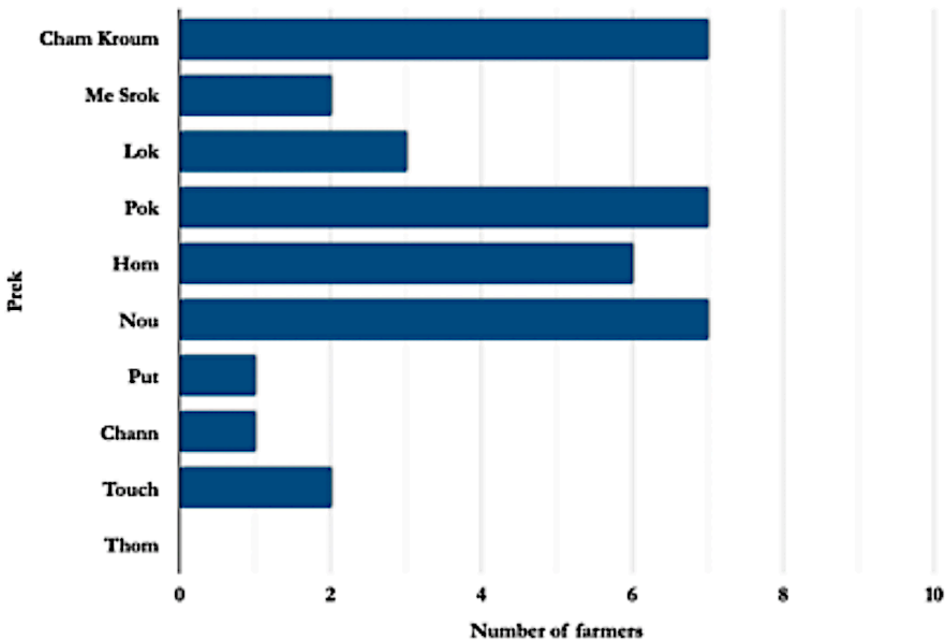


Figure 13. Number of farmers interviewed on each prek in the study area from North to South. Credit: C. Orieschnig.

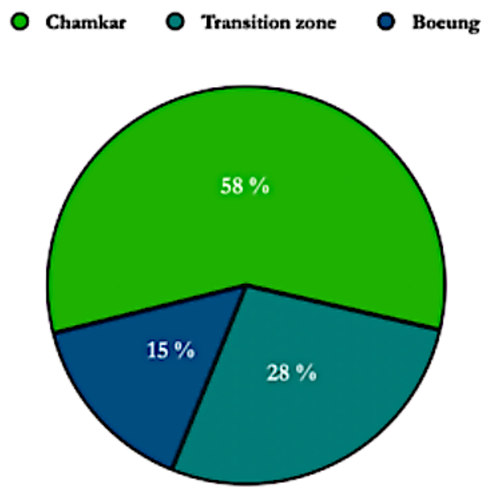


Figure 14. Distribution of plots surveyed among zones in the study area. Credit: C. Orieschnig.

2.2.2. Interviews with other stakeholders

Surveys were also conducted among two different classes of stakeholders in the study area: village chiefs and input sellers. The interviews with village chiefs, the results of which will mainly be used in the framework of C. Orieschnig's PhD project, are relevant to this thesis in so far as they provide more general organisational information at prek and village level. On average, village chiefs are 66 years old and have held their position for over a decade. Consequently, their long experience and their role as a central point of observation allowed for rich open discussions.

In order to complement the agronomic data provided by farmers, a survey was also conducted among input sellers in the study area. Indeed, input sellers play an important role as agricultural advisors in these campaigns, the younger ones often having received training in agro-chemistry. The questionnaire used was produced with the aim of answering questions on the quantity and price of the most frequently applied inputs in the area (Annex C). In total, six input sellers were interviewed along National Road 21 within the study area. The results have been used to create an inputs database for the study area (not presented in this thesis) and to detail crop budgets.

2.3. Estimation of irrigation volumes applied

2.3.1. Field measurements

The surveys provided information on irrigation schedules, including frequency and duration of irrigation sessions, but the systems' flow rates and therefore the volumes of water applied remain unknown. It is therefore necessary to estimate these flows according to the properties of the pumps studied. To this end, the following data were collected on 14 pumping stations:

Pump model	Engine power (HP)	Pipe material	Pipe inner diameter	Pipe length	Lift head ΔH	Qtheo	HMTtheo

2.3.2. Pump discharge and irrigation volume assessment

Discharge estimation was then computed trough the relation between hydraulic power, total head and pump discharge:

(1) $$Q = \frac{P_h}{\rho g HMT}$$

with Q being the discharge (m3/s), Ph the hydraulic power (W), ρ the water density (kg/m3), g the gravitational acceleration (m/s2) and HMT the total head (m). Hydraulic power is obtained from engine power (HP) data, assuming a pump efficiency of 0.4. The value of the total heads is estimated by means of lift heights field data and the computation of linear head losses using the Lechapt Calmon formula (Baume et al., 2013):

(2) $$j = a_1 \,.\, Q^{a_2} \,.\, D^{(-a_3)}$$

j being the linear head loss (mm/m), a1, a2 and a3 constants depending on the pipe material (roughness), Q the discharge (m3/s) and D the pipe inner diameter (m). The computation reliability is checked with the few discharge data that were given on site. This pumping flow rates assessment subsequently make it possible to estimate the actual irrigation volumes applied according to the cropping systems and their irrigation schedule.

2.4. Crop water requirements and yield reduction modelling

Drought impact assessment is performed by means of the FAO software CROPWAT 8.0. The objective is to model yield reductions of crops identified as impacted by drought according to the climatic and hydrological scenarios mentioned during the surveys . The model is based on environmental conditions (climate, soil) and agricultural practices (crop calendar, irrigation practices).

2.4.1.Crop water requirements

2.4.1.1. Calculation of reference evapotranspiration

The reference evapotranspiration (ETo) represents the potential evapotranspiration of a well-watered grass crop, and other crop water needs are directly linked to this climatic parameter. Reference evapotranspiration in the area is computed by means of the Penman-Monteith FAO method (Allen et al., 1998) as follow :

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

where

ET_0 - reference evapotranspiration [mm.day^{-1}],

R_n - net radiation at the crop surface [MJ.m^{-2} .day^{-1}],

G - soil heat flux density [MJ.m^{-2} .day^{-1}],

T - mean daily air temperature at 2 m height [°C],

u2 - wind speed at 2 m height [m.s^{-1}],

e_s - saturation vapour pressure [kPa],

e_a - actual vapour pressure [kPa],

e_s - e_a - saturation vapour pressure deficit [kPa],

D - slope vapour pressure curve [kPa °C^{-1}],

γ- psychrometric constant [kPa °C^{-1}].

Climate data (temperature, humidity, wind, sun hours, radiation) are extracted from the FAO CLIMWAT database at the Phnom Penh Pochentong airport meteorological station. ET0 is then computed for monthly intervals on CROPWAT (Annex D).

2.4.1.2. Crop data input

Information about cropping systems and calendars has been obtained thanks to the field survey. Additional information such as length of growth stages, crop factors and rooting depth is provided by the FAO database. An overview of crop data inputs is given Annex E.

2.4.1.3. Crop potential evapotranspiration

Crop water requirements are expressed as crop evapotranspiration (ETc) in unit of water volume per area and unit of time (mm/day). The calculation takes into account weather conditions and crop characteristics such as :

$$ET_c = K_c \, ET_o \tag{4}$$

where

ET_0 - reference evapotranspiration [$mm.day^{-1}$],

ET_C - crop evapotranspiration [$mm.day^{-1}$],

K_C - crop coefficient [dimensionless].

Reference evapotranspiration is computed as given formula 3, while the crop coefficient (Kc) is provided by FAO Irrigation and Drainage Paper No. 56 (Steduto and Food and Agriculture Organization of the United Nations, 2012).

2.4.2. Yield reduction assessment

Assessing the yield reduction caused by drought required the integration of soil and rainfall data as well as the irrigation modalities of the different cropping systems as inputs.

2.4.2.1. Soil data

Soil characteristics mainly differ according to the area along the preks. Indeed, a distinction has to be made between chamkar, transition and boeung areas:

- In the chamkar, the top soil has very little coherence and varies from red to light brown. The soil texture is sandy.
- In the transition area, sedimentary deposits are relatively frequent, the soils are silty (loamy-clay on the lower lands, loamy-sand on the higher lands).
- In the boeung, the soil is altered by flooding periods and supplied with alluvial materials carried by river water. The color varies from light brown to brown. Texture is more coherent, and it can be classified as a clay soil.

Further measurements (infiltration rate, porosity…) and soil profiles have to be done in order to precisely determine soil groups and phases. For now, soil data from the CROPWAT database has been used : black clay soil for the boeung, red sandy loam for the chamkar and red loamy soil for the transition area (Annex F).

2.4.2.2. Rainfall data and processing

The rainfall data used is from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) data archive (Funk et al, 2014). The CHIRPS data are daily, with a spatial resolution of 0.05 x 0.05 degrees (cells are 500m x 500m). The rainfall over the study area is therefore obtained as a daily average of the several cells composing it. Another advantage of the CHIRPS data is the length of the time-series (1986 - 2019), which allows frequency analysis.

In the context of the agronomic modelling, not all rain which falls is used by the crop. In fact, rainfall water reaching the root zone, called effective rainfall, represents the total amount of rainfall minus runoff and minus evaporation. To take into account those losses and their variation depending on the rainfall intensity, effective rainfall is computed according to the dependable rain method (Brouwer, 1986) :

$$Pe=0.8xP-25 \text{ if } P>75mm/month$$
$$Pe=0.6xP-10 \text{ if } P<75 \text{ mm/month} \quad (5)$$

With P the precipitations and Pe the effective rainfall in mm/month.

The effective rainfall thus calculated is the rainfall ultimately used to determine crop irrigation requirements (crop water requirements minus effective rainfall).

2.4.2.3. Climate and hydrological scenarios

The difficulty of this modelling lies partly in the great diversity of situations encountered depending on the cropping systems. Results from the farmers survey highlighted the multiple forms of drought which may be climatic (due to insufficient rainfall), hydrological (due to insufficient flood intensity and/or duration for recession crops; due to delayed flooding for early wet season crops), and in both cases access to irrigation water resources can be limited leading to situations of insufficient irrigation. Consequently, the water scenarios to be modelled are diverse, combinable, and dependent on the cropping systems studied.

The rainfall deficit is modelled by modifying the rainfall input variable in the software. In order to determine unusual « dry seasons », the seasonal rainfall deficit has been calculated as the difference between the reference evapotranspiration (ET0, from the Phnom Penh Pochentong airport meteorological station) and the monthly rainfall (CHIRPS data) for each year of the time-series. A frequency analysis of water deficit levels has been performed to assign a return period to them. As the objective of the study is to model relatively frequent rather than exceptional drought situations, the five-year return period has been be preferred.

In the case of a flood of insufficient intensity and/or duration, the transition areas are only flooded for a short time or not at all. As a result, recession crops are sown on soils with relatively less available soil moisture than in normal years. To model this effect, the parameter of the initial soil moisture depletion has been modified for the situations and areas concerned.

Finally, the issue of insufficient irrigation water resource (dry prek) has been modelled by modifying the irrigation calendar during the periods mentioned. For example, if farmers reported yield losses due to a dry prek between April and May, the irrigation data for the considered crop system has been be entered as zero during those two months.

The different types of scenarios are summarized in table 1, with all combinations of scenarios remaining possible depending on the survey results.

Table 1. Drought scenarios overview.

Drought causes	CROPWAT scenario
None	Control
Rainfall shortage/late monsoon	5-years return rainfall deficit
Low flood intensity/duration	Initial soil moisture depletion
Prek dry	No irrigation
Late recession	Recession crop calendar delayed

2.4.2.4. Yield reduction

The CROPWAT software allows the modeling of yield losses related to water deficit through the following expression:

$$1 - \left(\frac{Y_a}{Y_x}\right) = K_y\left(1 - \frac{ET_a}{Et_x}\right) \quad (6)$$

where Y_x and Y_a are the maximum and actual yields, ET_x and ET_a are the maximum and actual evapotranspiration, and K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses.

The maximum yield (Y_x) depends on the genetic of the crop variety and climate conditions, assuming that agronomic factors are not limiting. The maximum evapotranspiration (ET_x) is calculated as explained for the crop evapotranspiration, considering that crop water requirements are fully met (enough rainfall and irrigation). The actual evapotranspiration (ET_a) is computed under the specific situation of rainfall and irrigation practices entered which determine the available water for the crop. The yield response factor parameter (K_y) represents the complex biological, physical and chemical relationships between crop production and crop water use. The parameter is therefore crop and growth period (ripening, vegetative, flowering etc.) dependant. Values from the FAO Irrigation and Drainage Paper No. 33 (Doorenbos et al, 1980) have been used for this work. Finally, actual yield (Y_a) is estimated depending on water deficit periods and associated yield response factors.

3. Diagnosis of prek agriculture

3.1. Production means

3.1.1. Land

On average, households own two to three plots, forming a total area around 1.7 ha. Less than 10% of the respondents are renting land, exclusively small plots to complement the property (one more plot for cash crops or self consumption). There is a great diversity of land holding pattern encountered in the study area.

The current plot plan results mainly from the plot allocation during the Vietnamese occupation and the few following years at the beginning of the 1980's (Morel, 1996). The land redistribution has been rather unequal, depending on the size of the households and affinities with the regime. The region's history can thus partly explain the great diversity of land ownership that can be observed today.

In recent years, a secondary differentiation has been made with the development of new sources of income (not taking into account migratory movements). Some households have evolved towards an activity system where agriculture is not the main income anymore. Basically, one or two plots have been kept on the chamkar (sometimes just near the house) for cash crop production. However, there are only a secondary source of incomes, with the primary source being salaries from workplaces (teacher, bus driver…) or profit from small businesses. On the other hand, farmers for which farming is the main or the only income have had to extend their cropping areas to move beyond subsistence farming.

3.1.2. Labour force

In the majority of cases, agriculture is a family affair and the labour-intensive tasks (sowing, irrigation, harvesting) are carried out by several people (parents and children). There are certain exceptions, such as when agriculture is not the main income or when children leave the household. Less than 10% of respondents use labour force from outside. However, many mentioned mutual aid between neighbours at harvest time. In the cases where labour is paid, the workers are mainly members of the Cham ethnic group or landless farm labour. For one working day, the average wage is between 25000 and 50000 riel depending on the kind of activity (6.25-12.5 usd/day).

3.1.3. Capital

Non-agricultural activities have an important place in the majority of households. Depending on the type of production system, the income they generate may represent a greater or lesser proportion of the total income. The most frequent non-agricultural activities are: profit from small business (grocery or restaurant), salary from workplace, construction work, fishing. Very frequently, farmers declare having contracted a loan, still in the process of being repaid or already repaid. There are three ways to access credit:

- Large loans (1000 to 10000 usd) are generally contracted from micro-finance institutions (notably the Prasac company). They can be used to finance the purchase of agricultural equipment (pump, motor-tiller, motorbike...) and/or to finance other household expenses (children's schooling, house construction...). Monthly interest is between 1.2 and 1.5% over a few years (from 1 to 5).

- Smaller amounts (in the order of a few hundred usd) can be borrowed from neighbours or relatives, mainly to finance agricultural inputs (pesticides, fertilizers, irrigation costs) at the beginning of the season. In this case it is often an interest-free loan, paid back after the harvest.

- Finally, input sellers can also sell their products on credit at the beginning of the season, with monthly interest between 3% and 5%, to be repaid at the end of the season.

3.1.4. Irrigation

3.1.4.1. Water resources

The water resources used come from the prek irrigation canals for the vast majority of chamkar and transition area cropping systems. If the prek is dried out during the dry season, water can be doubly pumped from the Bassac to the prek and then from the prek to the plot. The prek then fulfils the function of a temporary reservoir. Into the boeung area, recession rice can be irrigated by pumping from the pounds where water has been retained during the rainy season, and from the canals at the end of the preks. In all cases encountered, surface water pumping was preferred. Farmers reported that they no longer use wells in the area due to arsenic contamination of groundwater.

3.1.4.2. Collective management of water resources

In the case of non-rehabilitated preks, there is no group officially in charge of the organization and maintenance of the prek. In case of problems (bank collapse, prek dry, vegetation issue etc.), water users organise among themselves to find a solution. A common financial pot can be set up to pay for maintenance, the water users may participate in the onsite work, and the village chief sometimes takes the lead in organising activities. Otherwise, pumping in the study area is free, the only limit being the availability of the resource. If the prek is dry during the dry season, water can be pumped from the Bassac to the prek. The operation may be carried out by the water users directly, sharing the pumping costs and agreeing on irrigation schedules. Pumping into the river can also be carried out by a private water seller who charges the water users for the operation.

In the case of rehabilitated preks, prek users committees (PUC) have been set up to collectively manage the resource. Nevertheless, these organisations seem to be little active and not very operational, despite the fee paid by the water users.

3.1.4.3. Pumping systems

The vast majority of irrigation in the prek area is carried out by means of disparate pumping systems, the properties of which are as follows (figure 15):

1. The pump is installed on the bank, or at half height if the slope allows it. Its lift height varies accordingly between 2 and 6 meters. The inlet pipe is made of PVC, with a variable inner diameter but often equal to 80mm. Its length varies according to the lift height and the distance to the source, between 3 and 8 meters.

2. The pumps used are of various origins (China, Japan, Thailand…) and models. Depending on the production system, their number varies between 1 and 5 pumps per farm. In the vast majority of cases, farmers own a pump that they move between plots according to the irrigation schedule. In the rare situations where the farmer does not own a pump (<5%), it can be provided by a family member or rented by the hour. In all cases, pumps run on petrol or diesel. Irrigation costs are therefore indexed to the oil price (3200 riel/l for petrol, 3500 riel/l for diesel in spring 2020). The information displayed on the pumps depends on the model, but most often includes the engine power (HP) and the connection diameter. Except in rare cases, flow rate is not indicated. As a result, farmers are rarely aware of the flow rate of their installation and therefore of the volumes of irrigation water applied. The results of the pump discharge estimation (Annex X) highlight the diversity of the pumps used, with flows ranging from 20 to 80 m^3/h and an average of about 60 m^3/h.

3. From the pump to the plot, the water is transported under pressure through layflat hoses, across the dirt roads along the prek. The length of the hoses depends on the distance between the pump and the irrigated area, and can be up to 200 metres in the case of end-of-plot irrigation without a secondary canal or appropriate furrows.

4. The irrigation type depends then on the cropping system, but consists in most cases of gravity irrigation (flooding or furrow).

Figure 15. Typical prek-plot pumping system in the study area, February-March 2020.

3.1.5. Agricultural market

The geography of the study area and its accessibility via National Road 21 allows the distribution of agricultural products to the markets of Phnom Penh (mainly fruits and vegetables), Vietnam and Thailand (mainly rice and fruits) via middle-men. Fruits and vegetables may also be distributed locally, through small business or direct selling at the Koh Thum marketplace. Average current market prices in spring 2020 for the main crops are displayed Figure 16.

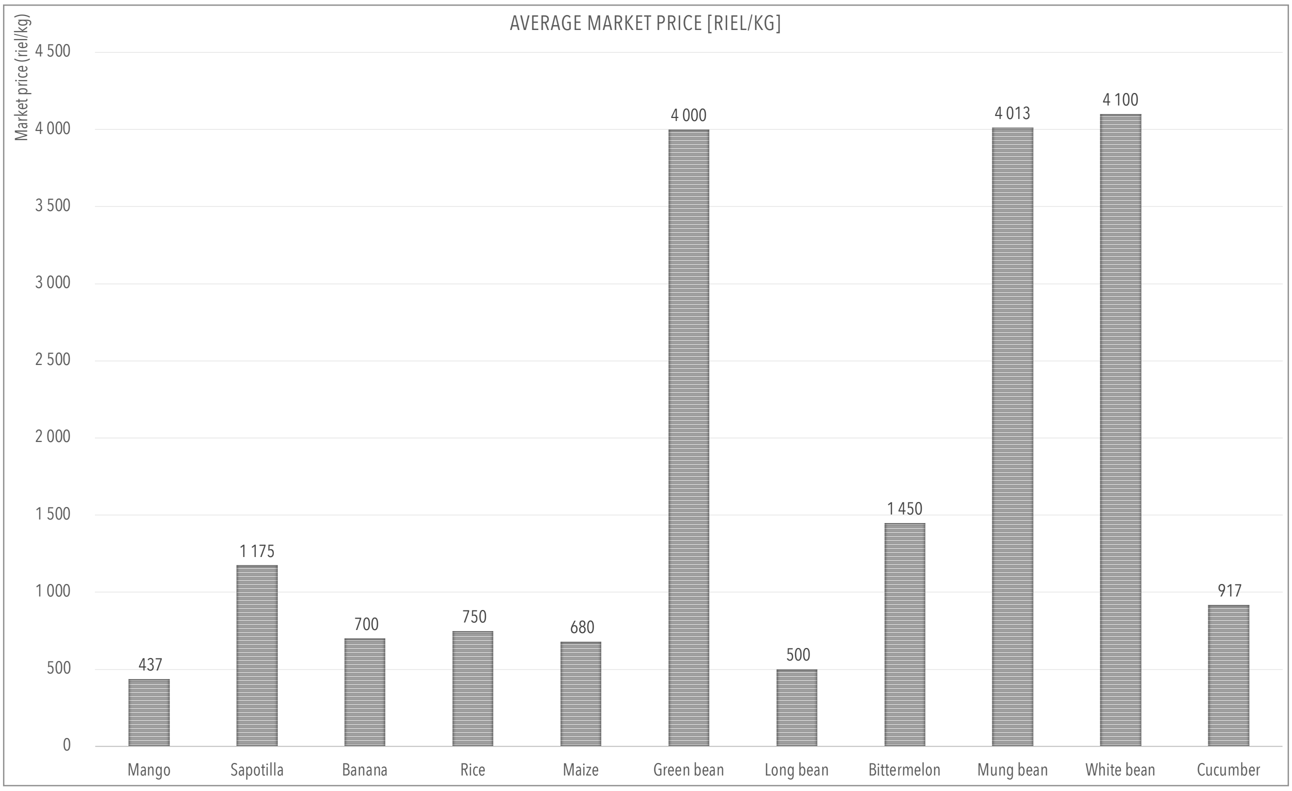


Figure 16. *Average market price of agricultural products, survey results, 2020.*

It is important to keep in mind that agricultural market prices are evolving and that these results therefore reflect a given period. What is noteworthy is the price per kilo of mango, which is particularly low. Farmers mention a great instability in the price of mangoes, which has recently dropped from an average of 800 riel per kilo to only 500 or even 300 riel per kg. This collapse can be explained by a sharp increase in supply, as farmers have started to grow mango on a massive scale, and demand that did not increase in parallel. The effects of COVID-19 are also already being felt, as Chinese buyers have been absent since January.

3.2. Cropping systems

The main cropping systems observed in the area are rice (recession rice, dry season rice, early wet season rice), fruit trees (mango, sapotilla, papaya, banana), vegetables (irrigated or not irrigated mung bean, green bean, long bean, white bean, cucumber, eggplant, bitter melon...) and maize (early wet season, wet season). Their relative importance in the study area in terms of surface area is shown in Figure 17.

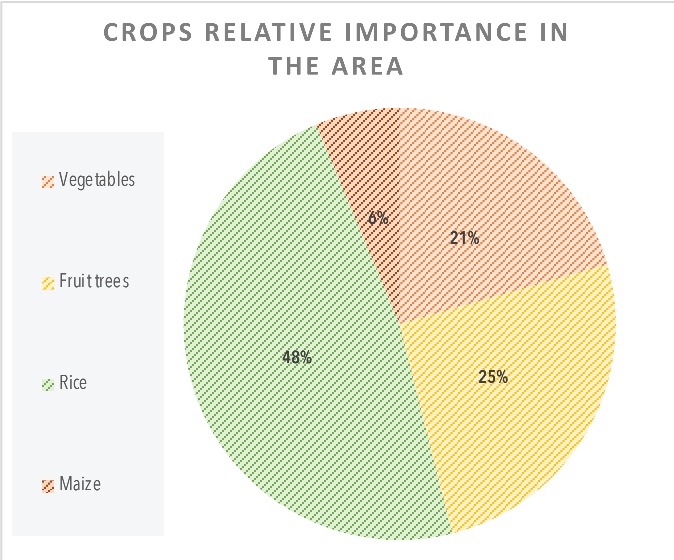


Figure 17. Crops relative importance in the study area, land use percentage.

From the survey results, the technical itineraries (Annex G) and average yields (figure 18) are determined for each cropping system.

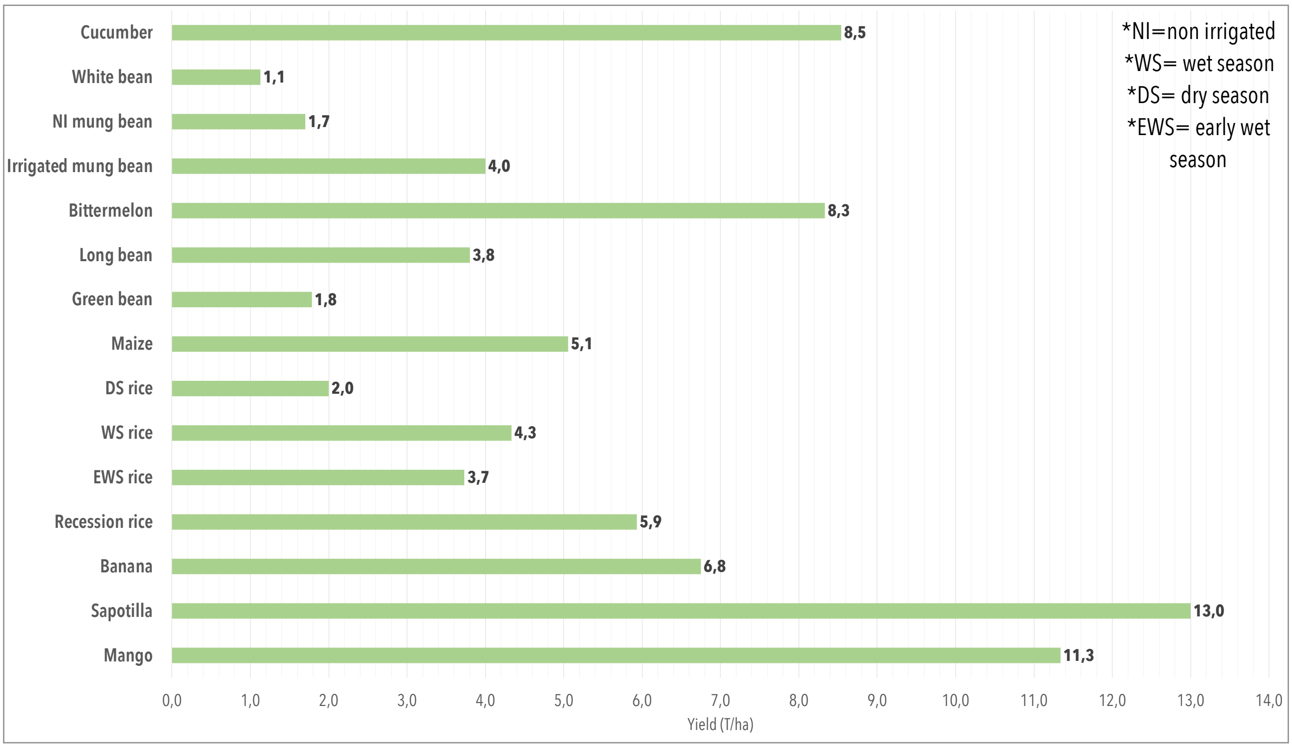


Figure 18. Crop average yields in the area, field survey results.

Crop budgets are based on this information, with intermediate consumption costs including equipment rental (harvest machine, motor-tiller, tractor), inputs (pesticides, fertilizers), pumping costs and labour costs. A breakdown of the gross agricultural products according to the main cropping systems is shown figure 19.

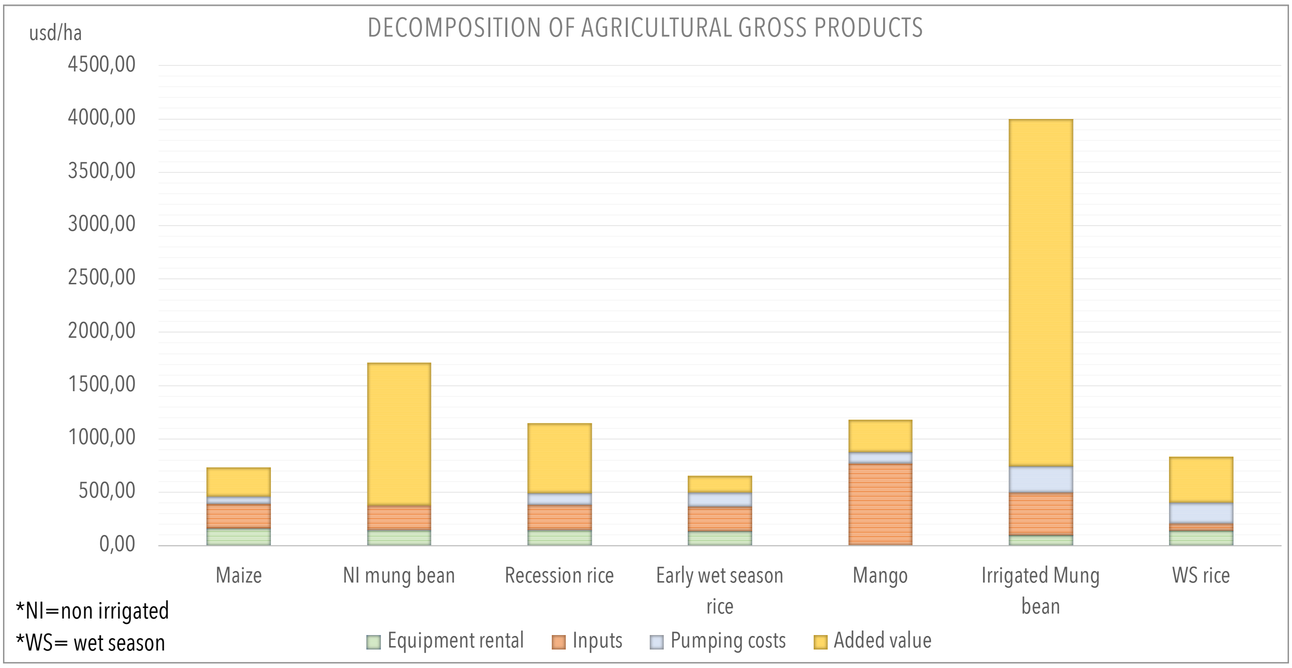


Figure 19. Decomposition of main cropping systems agricultural gross products, averaged values from survey results.

3.3. Production systems

The study area includes a great diversity of production systems, resulting from the spatio-temporal disparity in water availability and the variety of soil types. It is impossible to list them in their entirety, therefore this section will aim to identify the main trends encountered, with all the intermediate nuances remaining conceivable.

3.3.1. Landless - 15%

A significant portion of the farming households in the study area is landless. Under these conditions, agricultural land may be rented (on average 250usd/ha/year for a plot in the boeung, 150usd/ha/year in the chamkar) or cultivated under a sharecropping system. In the vast majority of cases, the landless live from livestock (chicken, cows), fishing and agricultural labour (broadcasting, harvesting). This is particularly the case for households belonging to the Cham ethnic group, whose village is on the edge of the prek Ambel, at the end of prek Cham.

3.3.2. Agriculture as secondary activity (SP1) - 38%

Within the Study Area, just under 40% of farmers practice agriculture as a secondary economic activity, meaning that agriculture represents less than 50% of their total annual income. The areas exploited are very small (less than 0.5 ha) to medium (between 1.5 and 2 ha), rarely large (between 2 and 4 ha). Total incomes vary greatly between people, depending mainly on the type of external activity (small business, salary from workplace) and the agricultural area owned. The production system has been divided into three sub-systems according to the cropping systems practiced.

3.3.2.1. Fruit trees only (SP1a)

Production sub-system SP1a includes households that exclusively grow fruit trees as a secondary economic activity. This is illustrated in figure X, which show the share of cropping systems in the sub-system plot plan (figure 20.a) and the proportions of sources of annual incomes per worker (figure 20.b). The cultivated plots are located on the chamkar area, often around the houses. The main cropping system is mango, which may explain the very low proportion of farming income with respect to total income, as mango prices have been at their lowest recently.

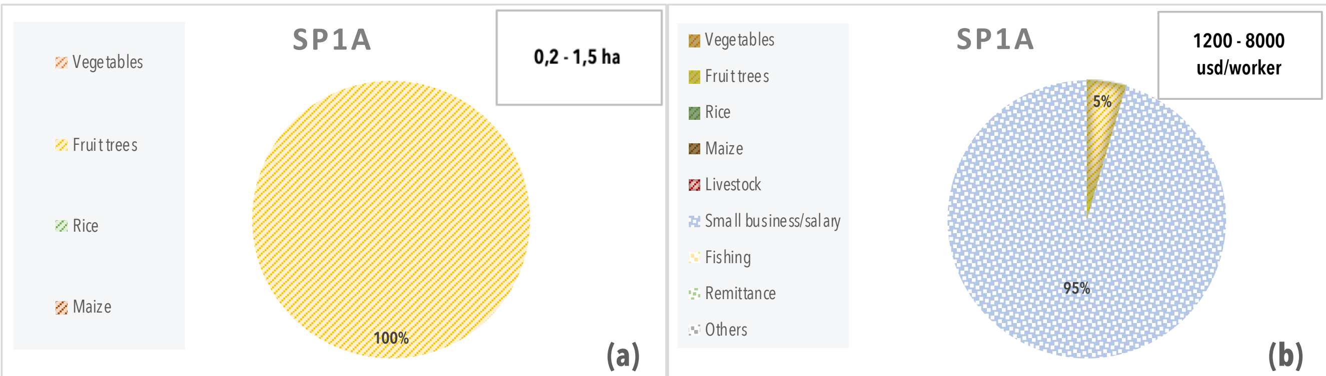


Figure 20. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.2.2. Fruit trees and vegetables (SP1b)

SP1b is similar to SP1a with the difference that cultivated area, which is slightly larger than for SP1a, is shared equally between fruit trees and vegetables. The higher added value of vegetables is expressed in the share of agricultural income, which makes up a larger part of the annual income than fruit trees (Figure 21.b). Older people can receive a remittance paid by their children on the occasion of national festivals (150 to 250 usd/year/child). This operation can be found in other systems, but SP1b farmers are older in average and thus appear more dependent on remittances. The rice plots (boeung) might have been sold because they were too labour-intensive for little added value.

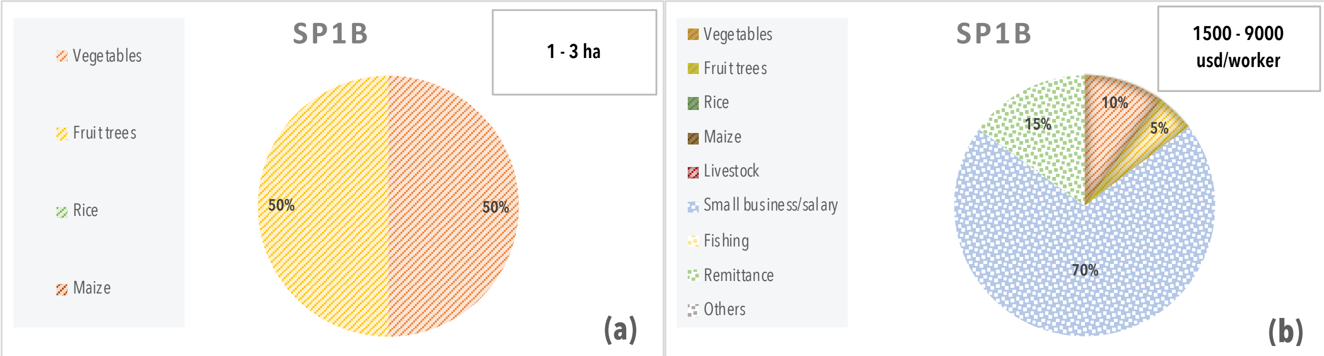


Figure 21. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.2.3. Rice, small areas (SP1c)

SP1c produces only rice, mainly during the recession period in the boeung (single cropping). Rice cultivation is carried out in combination with cattle breeding in all cases encountered. Overall, the total annual income is lower than in the other SP1s (different type of external activities), and agriculture accounts for a larger share of the income. However, a benefit is that households are self-sufficient in rice.

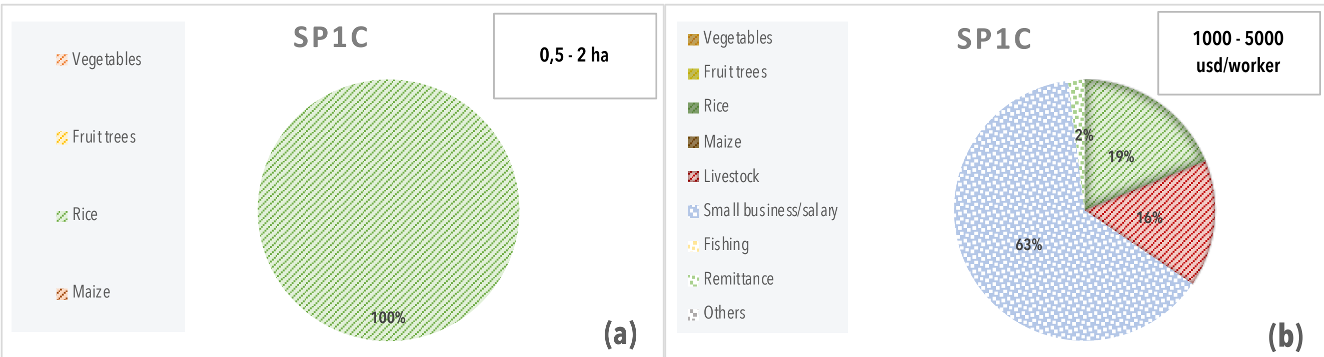


Figure 22. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.3. Agriculture as main activity - Specialists (SP2) - 15%

The SP2 production system represents a category of farmers for whom agriculture is the main source of income, and whose fields are located in a specific sub-area of the prek system. Overall, total revenues are lower than those of SP1 but the differences between subsystem individuals are less important. SP2 represents about 15% of the agricultural households in the study area and is divided into two sub-systems relatively to the cropping systems cultivated.

3.3.3.1. Rice, larger area (SP2a)

SP2a farmers are specialised in rice production, which is grown on all their plots and accounts for almost 80% of total income. The specialization of the activity is done on large cropping areas (up to 8 ha) and allows investment in equipment (broadcasting machine in addition to the classic pumps and sprayers). About 35% of households combine this production method with cattle breeding. Income may be supplemented by the profit from fishing.

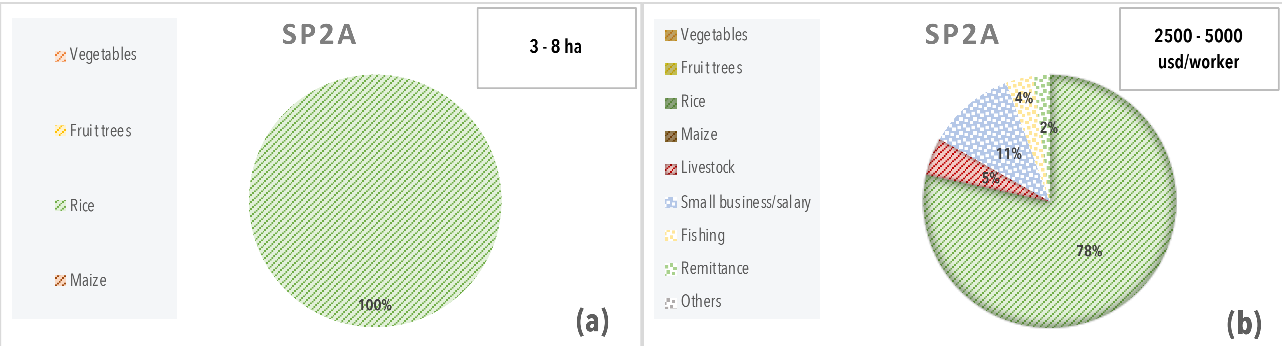


Figure 23. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.3.2. Fruit trees and vegetables (SP2b)

SP2b farmers concentrate their farming activities in the chamkar area. The cropping areas owned are small and are cultivated with fruit trees and vegetables. Again due to the mango crisis, the share of income from its cultivation is low despite its relative importance in the land use. On the other hand, the high added value of vegetables means that they account for more than half of total income. 50 % of farmers practice cattle breeding, which in this case represents a large share of the annual income (selling price can reach 850 usd/head). In some cases, a small external income (taxi driver, construction worker) can supplement the annual income.

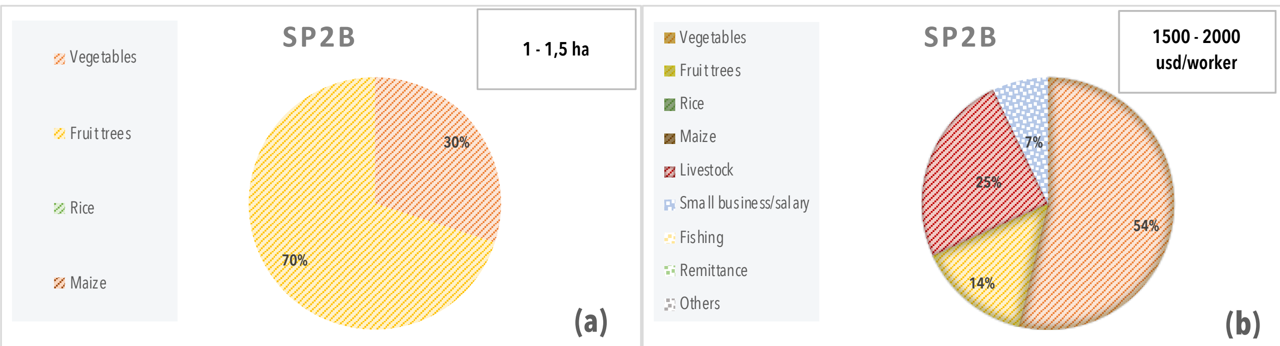


Figure 24. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.4. Agriculture as main activity - Polyculture (SP3) - 32%

This last major production system represents more than 30% of the farmers in the area. Agriculture is still the main source of income, but it is more diversified. The areas owned are medium to large. SP3 is divided into three sub-systems of production according to crop species and their rotations.

3.3.4.1.Fruit trees, vegetables and single cereal (SP3a)

SP3a is based on the cultivation of fruit trees, vegetables and a single cereal cropping (rice or maize). More than half of the farmers raise cattle, and most of the maize is produced as fodder. The area share of the rice, fruit trees and and vegetables cropping systems are balanced. Income shares are less so, with vegetables accounting for more than a third of total income and rice and fruit less than a fifth. The great variability in annual income within the sub-system is explained by differences in land and cattle sizes.

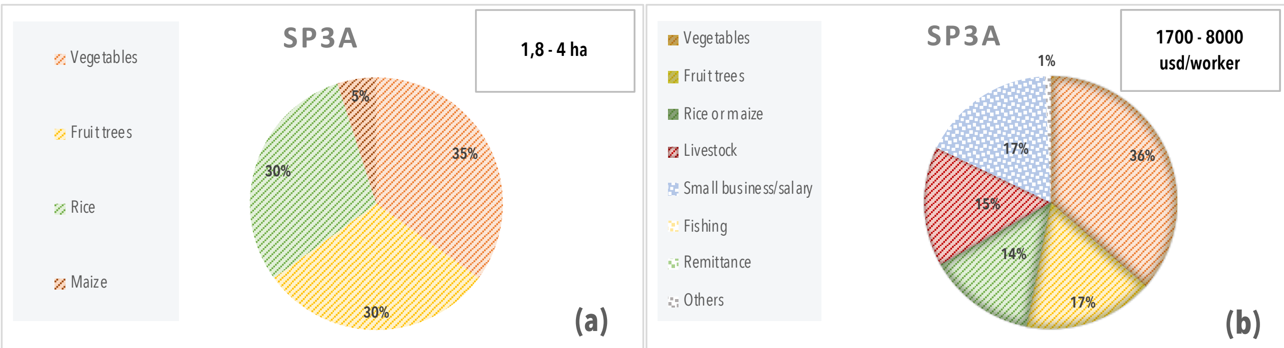


Figure 25. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.4.2. Cereals and vegetables (SP3b)

SP3b farmers mainly grow cereals (rice and maize) but have maintained a market gardening activity with an annual vegetable crop such as mung bean or white bean. Vegetables are grown in the transition area during recession and are generally non-irrigated. Maize is frequently grown in the early wet season on the same plots as a second cropping. Nevertheless, surveys show low yields and high intermediate consumption costs in this situation, which explains the low added value or even negative balance for this maize as second cropping. The annual income may be supplemented by external activities (wage labour, construction worker) and fishing.

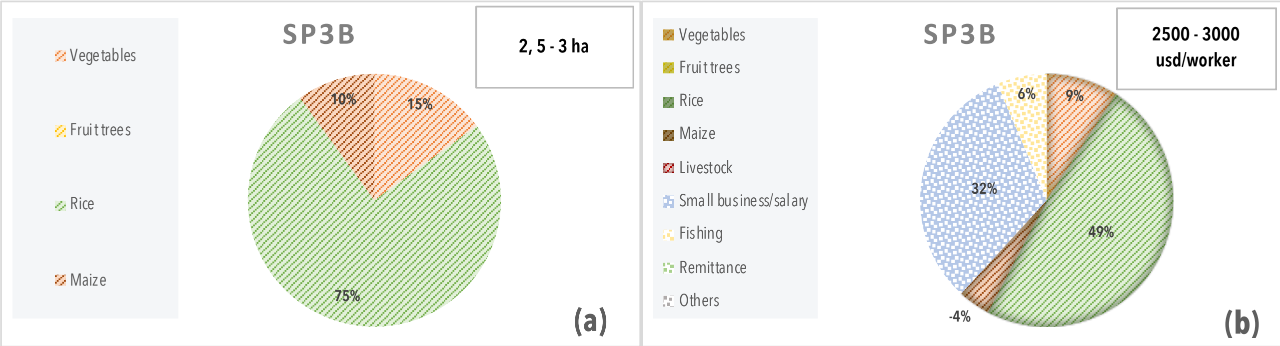


Figure 26. Cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.4.3. Fruit trees, vegetables and double cereal (SP3c)

Finally, SP3c is characterized by the cultivation of fruit trees, vegetables and cereal double cropping, which may correspond to rice double cropping (recession rice/early wet season rice) or maize/vegetable rotation. The cultivated area is large and may sometimes be expanded by renting additional land. Vegetables are grown intensively (irrigated and well supplied with inputs). The income is exclusively agricultural and allows for investments. Farmers in this production system often own a motor-tiller, which they may rent.

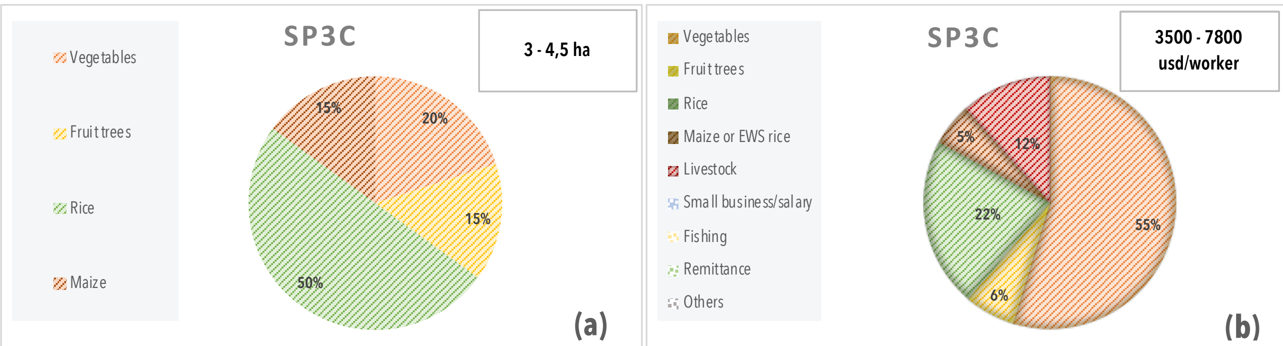


Figure 27. SP3c cropping systems share within sub-system agricultural area (a) and proportions of sources of annual income per worker (b).

3.3.5. Production systems overview

So far, this analysis has summarised the wide variety of situations encountered in the field. It has shown that around 40% of farmers in the study area earn a secondary income from agriculture by cultivating small to medium-sized areas. 15% of the peasants are landless and live from livestock breeding and agricultural labour. Finally, slightly less than half of the farmers live from agriculture as main source of income, practising monoculture or polyculture on larger areas.

These values, which represent the diversity of farmers, should be put into perspective by comparing the relative importance of production systems with respect to land use (Figure 28). Indeed, individuals in SP1 manage more than half of the orchards in the area but account for only 12% of vegetable production, 10% of rice production and 0% of maize production in terms of agricultural area. A summary table of production systems is given in figure 29.

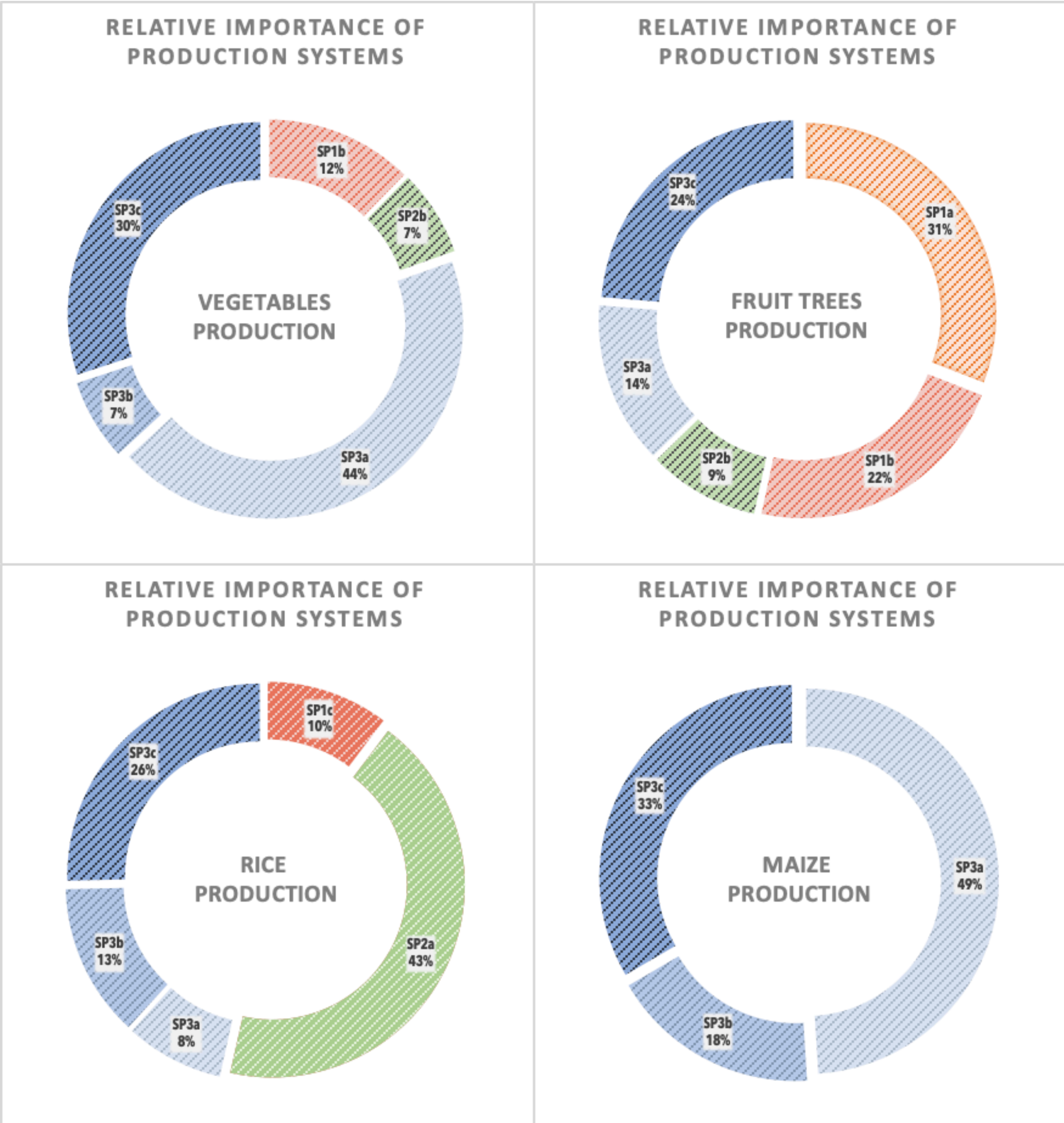


Figure 28. Relative land use importance of production systems within the study area.

Production system	Production system name	% PS	Production sub system	Production sub system name	Cropping systems	Cultivated area	Livestock (% of farmers)	Equipment	Plot rental (% farmers)	Agricultural income	Total income
SP1	**Agriculture as secondary activity**	**38%**	SP1a	Fruit trees only	Fruit trees	0,2 - 1,5 ha	No	Pump, sprayer	0%	0-700 usd/worker (5%)	1200-8000 usd/worker
			SP1b	Fruit trees + vegetables	Fruit trees Vegetables	1 - 3 ha	No	Pump, sprayer	0%	450-1200 usd/worker (15%)	1500-9000 usd/worker
			SP1c	Rice small area	Recession rice	0,5 - 2 ha	Cows 100%	Pump, sprayer	30%	750-850 usd/worker (30%)	1000-5000 usd/worker
SP2	**Agriculture as main activity Specialists**	**15%**	SP2a	Rice larger area	Recession rice Wet season rice Dry season rice	3 - 8 ha	Cows 35%	Pump, sprayer, broadcasting machine	0%	2000-4000 usd/worker (85%)	2500-5000 usd/worker
			SP2b	Chamkar cash crops	Fruit trees Vegetables	1 - 1,5 ha	Cows 50%	Pump, sprayer	0%	1400-1800 usd/worker (95%)	1500-2000 usd/worker
SP3	**Agriculture as main activity Polyculture**	**32%**	SP3a	Fruit trees + vegetables + single cereal	Fruit trees Vegetables Maize Recession rice	1,8 - 4 ha	Cows 60%	Pump, sprayer	20%	1700-8000 usd/worker (80%)	1700-8000 usd/worker
			SP3b	Vegetables + double cereal	Vegetables Maize Recession rice	2,5 - 3 ha	No	Pump, sprayer	0%	1000-2500 usd/worker (60%)	2500-3000 usd/worker
			SP3c	Fruit trees + vegetables + double cereal	Fruit trees Vegetables Maize Recession rice Early wet season rice	3 - 4,5 ha	Cows 40%	Pump, sprayer, motottiller	50%	3500-7800 usd/worker (100%)	3500-7800 usd/worker
SPL	**Landless**	**15%**	Agricultural workers							0-1000 usd/worker	0-1000 usd/worker
			Breeders								

Figure 29. Production systems summary table.

4. Systems' response to hazards

4.1. Drought impact on production systems

4.1.1. Survey results

Agricultural drought is cited as the cause of yield losses by more than 30% of the farmers surveyed. The most sensitive crops mentioned are maize, dry season vegetables and rice (recession, dry season and early wet season rice).

4.1.1.1. Dry season maize sensitivity

According to the survey, **70% of maize plots are affected by drought**, leading to **yield losses between 30 and 50%** depending on the severity of the episodes. In most cases, the drought occurs between May and June when the monsoon is delayed, affecting the end of the dry season maize cycle. By planting early wet season maize on the chamkar, farmers' objective is to limit costly irrigation at the end of the cycle by relying on May-June rainfall. The flood return is also expected in the case of preks drying out during the dry season. In these circumstances, a delay in the first rains and/or flooding will lead to water deficit, sometimes not compensable by irrigation.

Figure 30. Drought effects on dry season maze, prek Touch chamkar, 13/03/2020.

4.1.1.2. Dry season vegetables sensitivity

About **30% of the plots identified for vegetable cultivation are drought prone** according to the field survey. The most affected cropping systems are non irrigated mung bean and green bean. **Yield losses estimated**

by farmers are between 25 and 40% for these crops. Non-irrigated vegetables are grown just after the rainy season, on chamkar or in the transition zone following the flood recession. In most cases, yield losses appear to be related to insufficient rainfall and/or flood level resulting in lower than normal soil moisture during this period. The losses are moreover localised in the highest parts of the transition plots, areas not reached by the flood usually. In some cases, drought occurs during the second green bean cycle, between February and April, when average rainfall is lowest. Grown without irrigation, these rainfed crops are particularly sensitive to climatic and hydrological uncertainties.

Figure 31. Drought effect on mung bean cropped on the chamkar, prek Thom, 04/03/2020.

4.1.1.3. Rice sensitivity

More than 20% of the plots cultivated with rice are affected by drought according to the survey. The cropping systems concerned are early recession rice, dry season rice and early wet season rice. Yield losses vary a lot depending on the cropping system, the associated cropping areas and the state of the prek.

Recession rice can suffer from insufficient total available water due to non-existent or too short flooding, generally affecting plots in transition zones. It can also suffer from late sowing due to a long duration flood that delays access to the boeung. As a result, vegetative development and reproduction phase take place during the months most exposed to drought (low rainfall and water levels in the Bassac). Farmers who have experienced these situations report **yield losses of between 30 and 40% for recession rice**.

Dry season rice is mainly affected by drought on plots the irrigation of which depends on preks in which water availability is not guaranteed. In the case of a dry prek between February and April, the farmers concerned suggest two strategies: maintaining reduced irrigation, by double pumping from the Bassac to the prek and then from the prek to the plot, which is twice as expensive; or abandoning the plot if the expenses linked to pumping appear too high weighed against the potential benefits. **In the first case, average yield losses are 50%. In the second case, the entire production is lost.**

Early wet season rice, mainly grown in the transition zone, is preferred to dry season rice because the first rains and rising water levels are expected to ensure better availability of water resources. Nevertheless, a delay in monsoon precipitation and/or flooding can lead to hydric stress at the end of the cycle if the irrigation calendar is not adapted. The farmers affected report **yield losses in the order of 50% due to low rainfall and water levels during May and June.**

4.1.1.4. Summary of drought response survey

Survey results highlight that despite the fact that the study area is located in a delta with a tropical climate, climatic and hydrological uncertainties can lead to drought events with strong consequences for the agricultural sector (table 2). Different cropping systems appear to be sensitive to drought at different times and for different reasons. On the basis of field trip data, a model using the CROPWAT software makes it possible to more precisely identify the agro-economic impact of drought on production systems.

Table 2. Cropping systems response to drought, survey results summary.

<table>
<tr><th>Cropping system</th><th>Affected plots</th><th>Cropping areas</th><th>Water shortage period</th><th>Drought causes</th><th>Yield response</th></tr>
<tr><td>DS maize</td><td>70 %</td><td>Chamkar</td><td>April-May-June</td><td>Monsoon and flood delayed
Prek dry</td><td>[-30% ; -50%]</td></tr>
<tr><td>DS vegetables</td><td>30 %</td><td>Chamkar - Transition</td><td>January -February
March - April</td><td>No irrigation
Low flood intensity/ duration
Rainfall shortage</td><td>[-25% ; -40%]</td></tr>
<tr><td>Early recession rice</td><td rowspan="3">20 %</td><td>Transition-Boeung</td><td>January - February - March</td><td>Low flood intensity/ duration or late recession</td><td>[-30% ; -40%]</td></tr>
<tr><td>DS rice</td><td>Transition-Boeung</td><td>February - March - April</td><td>Prek dry</td><td>[-50% ; -100%]</td></tr>
<tr><td>EWS rice</td><td>Transition</td><td>May - June</td><td>Monsoon and flood delayed
Prek dry</td><td>[-40% ; –50 %]</td></tr>
</table>

4.1.2. Cropping systems drought response modelling

The modelling carried out using the FAO CROPWAT software aims at specifying the drought sensitivity level of crops identified as impacted during the survey. This approach is based on the use of two main indicators: the crop water requirements and the yield reduction.

4.1.2.1.Crop water requirements of drought-sensitive crops

The results obtained for the crop affected are displayed figure 32. Unsurprisingly, the crops most affected by the drought are those whose water requirement peaks occur during the dry season (December to May).

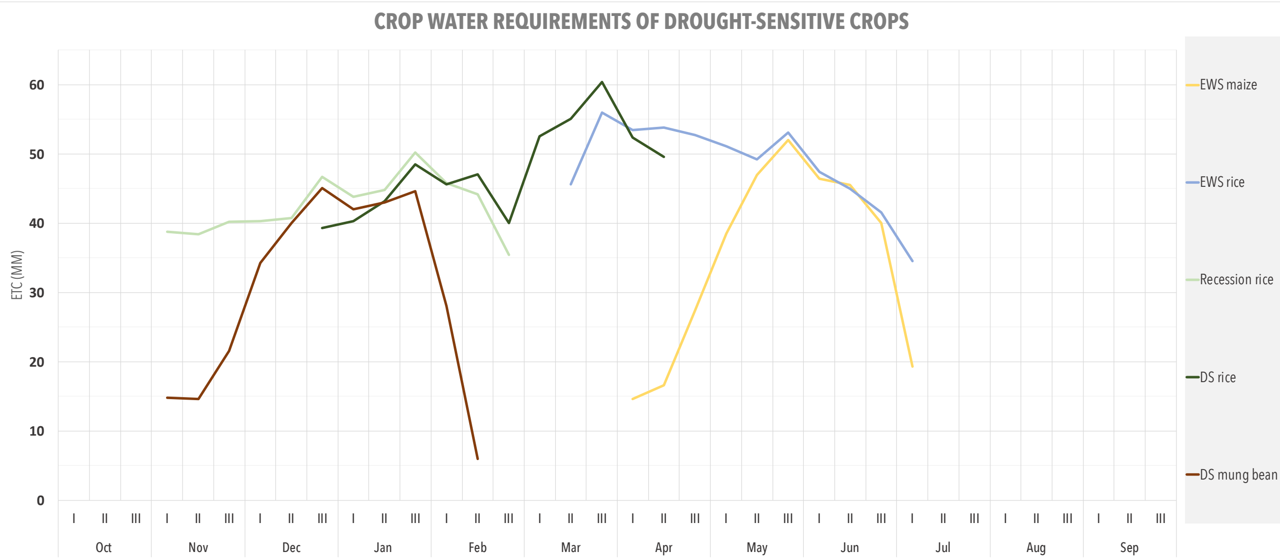


Figure 32. Crop water requirements of drought sensitive crops, CROPWAT results.

4.1.2.2. Yield reduction assessment

a) Evaluation of the drought effect on maize yield

Yield losses for early wet season maize are modelled under three scenarios:

- In the first case, access to irrigation water is guaranteed (prek water-filled) and rainfall corresponds to an early wet season (April, May, June) with a median rainfall deficit (1988, figure 33). Under these control conditions, the irrigation carried out is the typical irrigation provided by the farmers during the survey.

- In the second case, access to water in the prek is still guaranteed, therefore typical irrigation is possible. However, the monsoon is delayed, the rainfall corresponds to a seasonal rainfall deficit with a return period of about five years (2015, figure 33).

The third case represents a year when the monsoon is delayed and the prek water level is insufficient. The rainfall corresponds to the five year return period rainfall deficit (2015). The water resource being unavailable, typical irrigation cannot be performed.

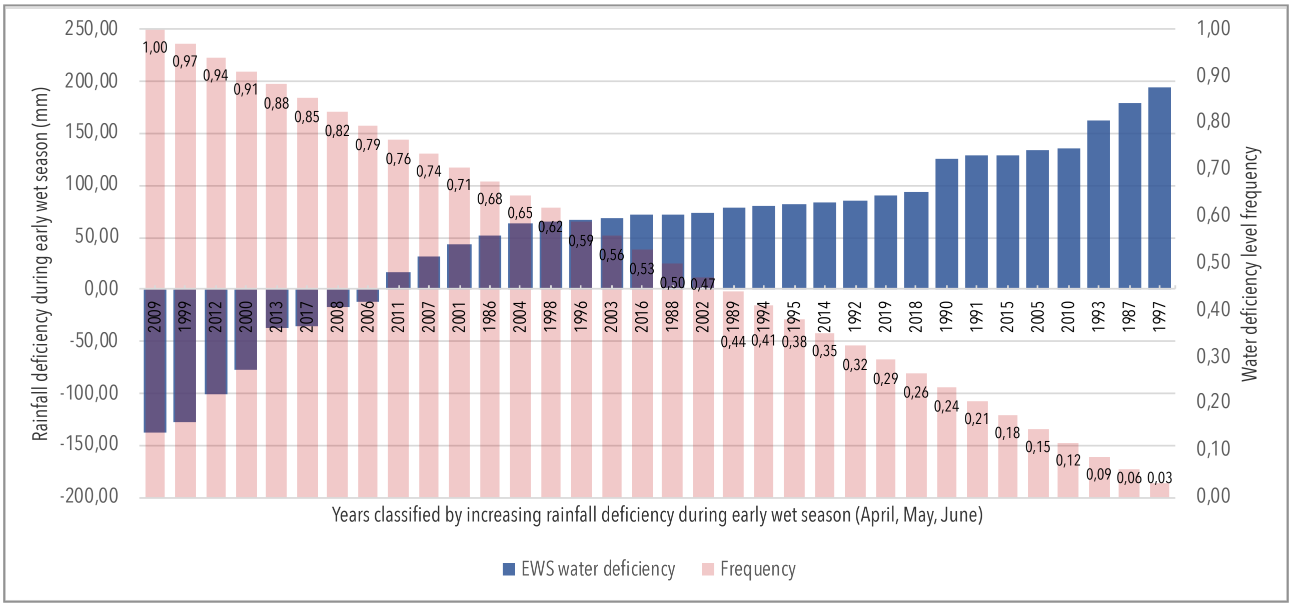


Figure 33. Frequency analysis of the early wet season rainfall deficit.

The results give an optimal yield for the control situation, a slight yield reduction (3%) in a rainfall deficit situation and a considerable yield loss (more than 30%) if irrigation is also impossible (table 3).

Table 3. Yield reduction modelling results for early wet season maize cropping.

Crop	Issue	Climate scenario	Irrigation practices	Yield reduction
EWS maize	Control	EWS median rainfall	Typical	0,00%
EWS maize	Monsoon delayed	EWS 5-years rainfall deficiency	Typical	3,00%
EWS maize	Monsoon and flood delayed/prek dry	EWS 5-years rainfall deficiency	No irrigation	31,60%

Thus the effect of precipitation shortage on production appears to be relatively small in the case illustrated. Nevertheless, irrigation volumes described by farmers as "typical" are high and indicate, for a season with median rainfall, an over-irrigation of maize (Annex H). It is certain that in the case of limited irrigation (availability or pumping costs issues), the rainfall shortage would have a greater impact on production. If water is unavailable in the prek, the situation most frequently mentioned is the abandonment of irrigation rather than double pumping from the Bassac. This can be explained by the low added value of maize, and therefore the farmer's lack of interest in carrying out an expensive operation.

b) Evaluation of the drought effect on dry season vegetables

Yield losses for dry season vegetables are modelled through the example of mung bean. As farmers indicated during the survey that they only experienced yield losses for non-irrigated vegetables during this season, the case of irrigated mung bean will not be studied. This may be explained by the fact that water availability is not a constraint during recession, also the lack of irrigation is part of the farmer's strategy. The following scenarios are proposed:

- The control scenario is made up of a recession season (from November to February) with a median rainfall deficiency level (2013, figure 34). Non-irrigated recession crops are mostly grown in the transition areas that were flooded during the rainy season. In order to model a sowing under optimal conditions, i.e. on well watered land, the initial parameter of soil moisture content is set to 100%.

- The second scenario is a season with a rainfall deficit corresponding to 5-year return period (2003, figure 34). The other variables and parameters remain unchanged from the control situation.

- In the third case, the objective is to model cultivation following a rainy season during which the intensity and/or duration of the flood were low. In these circumstances, transition area soils have not been refilled to the maximum of their water storage capacity. For modelling purposes, this is expressed with an initial soil moisture depletion of 50%. Rainfall deficiency during the season is nevertheless median (2013).

- The last case is that of a recession cropping season with a 5-year rainfall deficit (2003) sowed on soils insufficiently refilled by the flood (initial soil moisture depletion 50%).

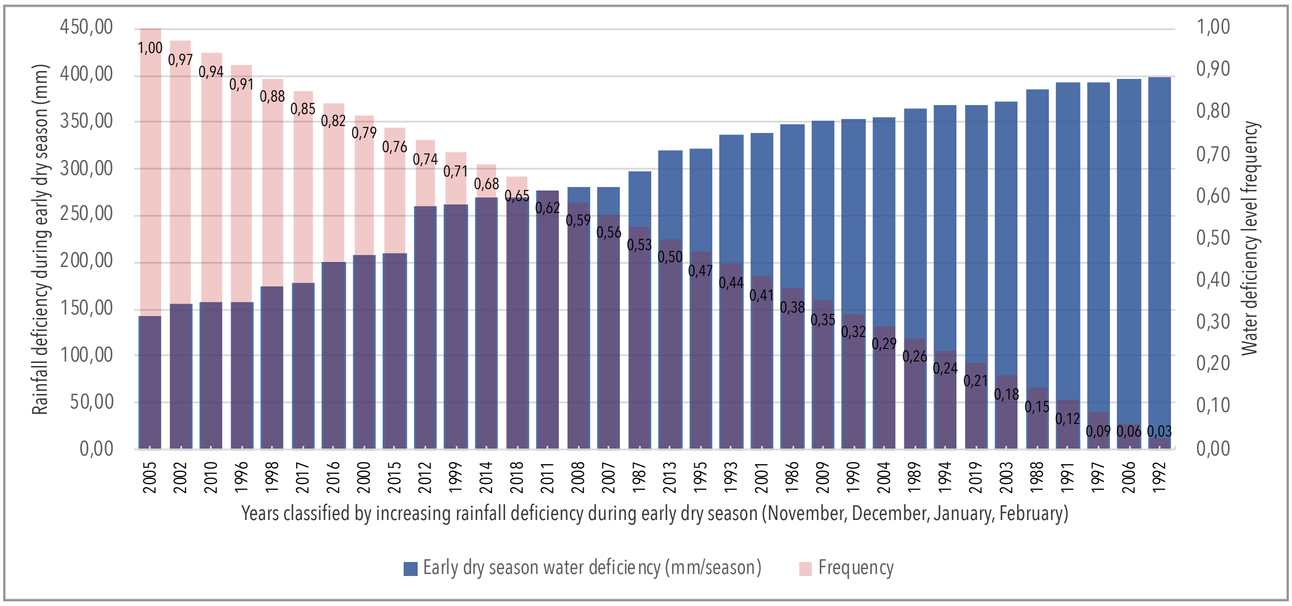


Figure 34. Frequency analysis of the early dry season rainfall deficit.

The results (table 4) show a yield reduction of more than 30% for the control situation, compared to an optimally irrigated mung bean (maximum yield). Seasonal rainfall deficits lead to a yield loss of around 37%, i.e. a 6% reduction compared to a season with a median rainfall deficit. The initial soil moisture depletion seems to have an impact in the same order of magnitude, although slightly lower (34.2% yield reduction). Finally, the combination of a 5-years return rainfall deficit and sowing on insufficiently refilled soil results in a yield reduction of around 45% compared to an irrigated mung bean, i.e. a loss of around 15% compared to the control situation.

Table 4. Yield reduction modelling results for dry season mung bean cropping.

Crop	Issue	Climate scenario	Irrigation practices	Yield reduction
DS mung bean	Control	DS median rainfall	No irrigation	30,6%
DS mung bean	Rainfall shortage	DS 5-years rainfall deficiency	No irrigation	36,9%
DS mung bean	Low flood intensity/duration	DS median rainfall Initial soil moisture depletion	No irrigation	34,2%
DS mung bean	Rainfall shortage Low flood intensity/duration	DS 5-years rainfall deficiency Initial soil moisture depletion	No irrigation	43,6%

The results obtained through the modelling match the orders of magnitude given by farmers during the field survey. Indeed, yield losses for vegetable crops at the beginning of the dry season appear to lie between 25 and 40% depending on climatic conditions. Although the values obtained for mung bean cannot be strictly applied to the entire diversity of vegetable crops cultivated in the area, the hypothesis of a similar drought response (with the same orders of magnitude) from other vegetable cropping systems will be made for the rest of the analysis. In general, it appears that the absence of irrigation makes these cropping systems vulnerable to drought, with high variability in yield under different climate scenarios.

c) Evaluation of the drought effect on rice

Rice yield losses are modelled for the three types of rice affected by drought. The multiple possible scenario combinations based on the survey results have been reduced to a control situation under median rainfall conditions for the relevant cropping period, and to an « extreme » scenario modelling losses if the situation cumulates poor cropping conditions (cf. bellow). The scenarios proposed for each type of rice are as follows:

- In the case of early wet season rice, the worst conditions mentioned by farmers are a delayed monsoon (rainfall shortage) and a delayed flood, making it impossible to irrigate between May and June. To model this situation, the rainfall data entered in CROPWAT are those of an early wet season with a 5-year return rainfall deficit, and irrigation is zero from May to harvest.

- In the case of recession rice, the worst situation is that of a late recession delaying the sowing date combined with a rainfall deficit between February and April. In the worst case, irrigation water is unavailable during this period. In CROPWAT, the crop calendar is thus shifted to an early January sowing date. The rainfall data used for the modelling is that of a year with a 5-year return rainfall deficit, and no irrigation is performed between February and the harvest.
- Finally, for dry season rice, the worst situation is modelled by entering in a 5-year return rainfall deficit season, while the prek drought leads to zero irrigation from February onwards.

The modelling results are shown table 5. Under control conditions, the maximum potential yield of early wet season rice is reached. A delayed monsoon and limited irrigation during the vegetative phase lead to a yield loss of more than 10%. Under conditions of median seasonal rainfall and typical irrigation, the recession rice reaches a yield close to its maximum potential (reduction of 0.4%). A rainfall deficit combined with limited irrigation leads to a sharp decrease in yield (more than 70%). Finally, dry-season rice also shows little loss if rainfall is median and typical irrigation practices are followed (2%). Under a rainfall deficit and limited irrigation scenario, yield losses are over 60%.

Table 5. Yield reduction modelling results for rice cropping.

Crop	Issue	Climate scenario	Irrigation practices	Yield reduction
EWS rice	Control	EWS median rainfall	Typical	0,00%
EWS rice	Monsoon and flood delayed/prek dry	EWS 5-years rainfall deficiency	Limited irrigation	10,50%
Recession rice	Control	DS median rainfall	Typical	0,40%
Recession rice	Late recession/rainfall shortage	DS-EWS 5-years rainfall deficiency	Limited irrigation	70,80%
DS rice	Control	DS median rainfall	Typical	2,00%
DS rice	Rainfall shortage/Prek dry	DS 5-years rainfall deficiency	Limited irrigation	63,00%

The results obtained through modelling are consistent with the survey results in the case of dry season rice. In contrast, the scenarios used for recession rice and early wet season rice give different results from the field survey, with recession rice appearing more impacted and early wet season rice appearing less impacted by drought than mentioned by the farmers. These differences may be explained by the simplifications made in the modelling, particularly concerning the land preparation parameters for rice cultivation. Indeed, due to the absence of precise data on this practice and for model simplification reasons, the land preparation parameters were entered identically for the different types of rice. In reality, however, there are major differences, recession rice being sown after the flood and therefore not requiring land preparation and early wet season rice being sown after the dry season and therefore requiring a land preparation phase. As a result, the initial levels of soil water saturation are likely to be different for different types of rice, which impacts the water balance and thus the actual yield losses. In this context, the significance of values can be discussed, especially for the slight deviations observed in control cases. Nevertheless, it remains true that the modelling reflects probable situations, and the results will therefore be used in the rest of the study.

4.1.3. Agro-economic consequences at the production systems scale

In order to determine the economic consequences of drought for the different production systems, the total income reduction is calculated by considering the extreme scenarios for each affected cropping system (table 6). These results are classified according to an impact scale. The impact is zero if the total income reduction is zero, very low if the reduction is less than 2%, low between 2% and 4%, medium between 4% and 6%, high between 6% and 8% and very high above 8%.

Table 6. Drought impacts on production systems.

Production system	Impacted cropping systems	Total income reduction	Drought impact	Impact score
SP1a	None	0	Zero	0
SP1b	Vegetables	1,3 %	Very low	1
SP1c	Recession rice	2,7 %	Low	2
SP2a	Recession rice EWS rice DS rice	7 %	High	4
SP2b	Vegetables	7,1 %	High	4
SP3a	Recession rice Vegetables Maize	6,7 %	High	4
SP3b	Vegetables Maize Recession rice	5,3 %	Medium	3
SP3c	Vegetables Recession rice EWS rice Maize	10,2 %	Very high	5

SP1a is not affected by drought as fruit cropping systems were not mentioned as being sensitive. The impact on SP1b and SP1c is respectively very low and low, due to the low share of agricultural income in their total income. SP2a, SP2b and SP3a are highly impacted by drought because the sensitive crops account for a large proportion of their total income. SP3b is moderately impacted due to non-farm income. Finally, SP3c is the most heavily impacted, since more than 10% of its total income, exclusively agricultural, is threatened in case of drought.

4.2. Flood impact on production systems

4.2.1.Survey results

Flooding is named as the cause of yield losses by approximatively 30% of farmers. The most sensitive cropping systems are early wet season rice, maize, wet season rice, recession rice and mango.

4.2.1.1. Early wet season rice sensitivity

According to the farmer survey, **nearly 75% of the early wet season rice plots have recently been flooded**, resulting in **yield losses of about 50%**. The losses occur between June and July, at the end of the rice cycle, in years of early flooding. Farmers particularly mentioned the years 2017 and 2018 to refer to this phenomenon. The plots concerned are located in the transition area, and usually experience little or no flooding at this time of the year. In case of early and intense flooding, farmers mentioned that water levels sometimes rise higher than one meter on the lowest areas of the plots, destroying the rice plants.

4.2.1.2. Early wet season maize sensitivity

More than 30% of the maize plots are exposed to flooding, resulting in **yield losses between 30% and 50%**. Cultivated on transition areas, maize is also threatened by the unpredictability of the flood arrival date at the beginning of the wet season.

4.2.1.3. Wet season rice sensitivity

Almost 30% of the wet season rice plots are prone to flooding and the resulting **yield losses are between 40 and 50%.** Wet season rice is rather cultivated on the upper part of the transition area, and in some instance on the chamkar. The flooding periods mentioned are between September and October, due to particularly intense flood peak that may be associated with heavy rains. Poor drainage of the plots could also aggravate the situation.

4.2.1.4. Recession rice sensitivity

In the vast majority of cases, recession rice is not exposed to flooding because seeds are broadcast after the flood, by default. Nevertheless, **a little more than 5% of the plots studied suffered yield losses of around 25%** following heavy rains at the beginning of the vegetative phase (tillering). In the case of poorly levelled plots (depressions) or poorly drained plots, flaking following heavy rains can last and drown the young plants. The farmers concerned explain that they sowed too early, thinking that the monsoon was over, and were surprised by late heavy rainfall at the end of October or early November.

4.2.1.5. Mango trees sensitivity

Mango trees are also exposed to flooding and **about 15% of the plots are affected**. On these plots, farmers estimate that they **lost between 10% and 20% of the trees**. Exclusively cultivated on the chamkar area, mango trees are impacted by the flood at the end of the plots, an area with a lower topography usually leading to a drain parallel to the prek channel. In the situations encountered, the young trees, which are more fragile, were asphyxiated by long-term flooding (more than a month), due to the low topography and probably poor drainage (figure 35). In some cases, young trees have been uprooted by the water flow. The period mentioned corresponds to the flood peak, between September and October.

Figure 35. Dead mango trees following a flood event at the end of a chamkar plot, prek Me Srok.

4.2.1.6. Summary of flood response survey

The results of the survey highlight the exposure of many farming systems to flood hazard, which is problematic when its intensity or temporality are unusual. The systems' response varies according to the crops and their production area. The extreme yield loss values will be used as a basis to assess the flood consequences at the production systems scale. Survey results are displayed in table 7.

Table 7. Cropping systems response to flood, survey results summary.

Cropping system	Affected plots	Cropping areas	Flooding period	Flood causes	Yield response
EWS rice	75 %	Transition	June - July	Early flood	-50 %
EWS maize	30 %	Transition	June - July	Early flood	[-30%; -50%]
WS rice	30 %	Upper transition, chamkar	September - October	Intense flood peak/ heavy rainfall	[-40%;-50%]
Recession rice	5 %	Boeung, transition	end of October, November	Late heavy rainfall	-25 %
Mango	15 %	Chamkar	September - October	Intense flood peak/ bad land management	[-10%;-20%]

4.2.2. Agro-economic consequences at the production systems scale

As for droughts, the impact of floods on production systems is estimated from the total income reduction calculation (table 8). The same impact scale is used, but a factor reflecting the temporal extent of the damage is added. Indeed, the consequences of the loss of perennial crops, when considering the annual financial balance, are identical to the loss of annual crops. However, the losses are long-lasting since the trees will have to be replanted (with a latency of 3 years for production) or, more likely, will not be replaced in view of the investment risk. Therefore, production systems that are durably affected by the floods will have their impact rating increased by one point.

Table 8. Flood impacts on production systems.

Production system	Impacted cropping systems	Total income reduction	Temporal extent of damage	Flood impact	Impact score
SP1a	Mango	0,1 %	Long term	Low	2
SP1b	Mango	0,2 %	Long term	Low	2
SP1c	Recession rice	0,2 %	Short term	Very low	1
SP2a	Recession rice WS rice	5,5 %	Short term	Medium	3
SP2b	Mango	0,2 %	Long term	Low	2
SP3a	Mango Maize Recession rice	0,7 %	Long term	Low	2
SP3b	Maize Recession rice	0,6 %	Short term	Very low	1
SP3c	Mango Maize Recession rice EWS rice	5,2 %	Long term	High	4

4.3. Production systems' adaptation capacity

The production systems' adaptation capacity to hazards is estimated on the basis of three indicators: diversity of activities (non-agricultural income and contribution to total income), crop diversity (number of cropping systems cultivated) and flexibility (inclination to innovation, farm decision plans). The adaptability levels are established through the decision tree displayed in Annex I.

Diversification of activities is a means of stabilizing household income, which can facilitate investment and serve as insurance in case of climatic hazards. The income generated can complement a main agricultural activity (SP2a, SP2b, SP3a, SP3b) or account for the majority of annual income (SP1).

The diversity of the cultivated cropping systems makes it possible to spread out work peaks over time and thus to cultivate larger areas or to keep time for other activities (livestock farming, fishing…).In addition, diversification limits risks in the face of climatic hazards since the crop calendars and cultivation areas are disparate. In the study area, systems are considered diversified if they cultivate at least 3 different main cropping systems occupying several cropping areas (SP3).

Flexibility is a rather sociological notion, highly dependent on the individual. It represents the inclination of farmers to innovate and change farming practices. It is a difficult indicator to determine at the production system scale, however the following trends emerge:

- Within SP1, agriculture is a secondary economic activity. Outside activities leave little time for agricultural change, and the land area cultivated is often too small to justify investment in equipment. Flexibility is therefore low.

- SP2a production systems have large areas under monoculture, which allows investment in specialised equipment that saves rental costs and allows service delivery to other farmers. Moreover, the diversity of cultivated areas (boeung, transition and chamkar) allows for diversification of rice types (recession, dry season, wet season). Surveys show that most farmers in SP2a have chosen to abandon early wet season rice cultivation, which is too exposed to hazards. The dry season rice is safer, with double pumping from the Bassac if necessary. The system is therefore considered flexible.

- SP2b farmers only cultivate the chamkar area. Many have switched to mango cultivation because of the interesting market prices a few years ago and in order to limit yield losses, especially on maize. This shows an ability to make decisions adapted to the economic and climatic context. The system is flexible.

- The SP3s operate in polyculture and have shown great flexibility through evolving strategies in crop calendars and spatial crop management taking into account flood variability. Maize, which still occupies a prominent place in the system's land use, is gradually being abandoned in favour of the cultivation of vegetables (generally mung bean), which have higher added value and are less sensitive to hazards.

5. Production systems' vulnerability

The assessment of production systems' vulnerability is based on the integration of the results of hazard impacts study and systems' adaptation capacity. Thus, the higher the exposure and sensitivity to hazards and the lower the systems adaptation capacity, the greater the vulnerability, and vice versa. Hence, vulnerability score is computed by adding the impact scores and subtracting the adaptation capacity score. The results are shown below (table 9). With a score between 0 and 2, the production systems vulnerability is considered as very low, low between 2 and 4, medium between 4 and 6 and high above 6.

Table 9. Production systems vulnerability to climatic hazards.

Production system	Drought impact	Flood impact	Adaptation capacity	Vulnerability score	Vulnerability
SP1a	0	2	2	0	**Very low**
SP1b	1	2	2	1	**Very low**
SP1c	2	1	2	1	**Very low**
SP2a	4	3	2	5	**Medium**
SP2b	4	2	2	4	**Medium**
SP3a	4	2	3	3	**Low**
SP3b	3	1	3	1	**Very low**
SP3c	5	4	2	7	**High**

The results show four levels of system vulnerability:

- The vulnerability of SP1a, SP1b, SP1c and SP3b is very low. Indeed, SP1s, although impacted by hazards, are ultimately only slightly dependent on agricultural incomes. The diversification of their economic activities is an insurance against agricultural risk. SP3b, which is more affected by drought than flooding, shows a good adaptive capacity due to the diversity of its income and cropping systems and the development of strategies in production practices.

- The level of vulnerability of SP3a is rather low because, although relatively strongly impacted by hazards, the diversity of economic activities and cropping systems, as well as changes in agricultural practices show that adaptive capacity is high.

- The so-called « specialists » production systems (SP2) appear to be moderately vulnerable to hazards. They are highly impacted by climatic hazards and the low diversity of cropping systems reduces adaptation capacity.

- Finally, the most vulnerable production system is SP3c. Cultivated cropping systems are diverse but highly impacted by hazards (especially EWS rice and maize). Moreover, the lack of non-agricultural income makes the financial health of the system totally dependent on agriculture.

Discussion and conclusion

The diagnosis carried out in the study area has highlighted the great diversity of the agricultural world observable in the prek region. The formulated assumption is that of a good representativeness of the region through the study of this area, which includes different hydrological situations in relation to the variable topography and developments between the prek systems. However, some factors could be at the origin of important differences according to the systems geography. For example, agricultural markets are necessarily different depending on the distance from the capital, or the proximity to the Vietnamese border. Disparities between local practices (collective resource management, importance of livestock or other) may also exist. The study of geographically remote areas (preks along the Mekong, proximity to Phnom Penh, proximity to Vietnam) should enable a regional diagnosis that takes these differences into account.

Within the prek systems, several agro-ecological zones are cultivated by households with heterogeneous means and practices. This study has tried to extract the common features of these zones in order to organize them into production systems. This stage, although based on survey work data, is already subjective and reflects the observer's view of the study area. Furthermore, the small number of interviews conducted may have consequences on the representativeness of the surveys.

Modelling the sensitivity of cropping systems to drought has made it possible to specify the crops' response to different climate scenarios in terms of yield. The comparison of the CROPWAT results with the survey results shows a satisfactory correspondence between the two ways of analysing the crop sensitivity to drought, the orders of magnitude being concordant with few exceptions. Nevertheless, the modelling process involves many uncertainties, especially concerning the soil data for which a field analysis was initially planned. In addition, the uncertainty of the estimation of pumping discharges is carried over into the integration of irrigation practices in the modelling. The assessment of actual irrigation volumes could be refined by statistical analysis of the pump models used, but remains difficult in view of the high variability of the models and changing pumping conditions.

The area's exposure to flooding has been described in general terms based on MRC data and the first remote sensing analyses carried out. At the scale of production systems, exposure was defined through survey work. In order to refine the analysis, additional work studying the spatial and temporal variations of the flood, and in particular its relation with the water levels of the Bassac, would be welcome.

Estimating the adaptation capacity of a system is a difficult task. At the origin of the project, the size of the survey sample should have allowed a statistical analysis of the actions in response to the hazards within the production systems. An extended data collection should allow this approach, in order to go further than the qualitative analysis given is this study, especially concerning the flexibility indicator. Moreover, the study of adaptive capacity deserves to broaden the proposed framework. For example, in response to the question concerning strategies deployed to face hazards, many farmers mentioned the importance of collective risk management, at the level of a water users community or at the scale of the prek system such as collaborating to supply the prek with water from the Bassac during droughts or collectively constructing earth dikes within the canal to avoid early flooding or concentrate sparse amounts of water during the dry season. Moreover, the rehabilitation of the preks is seen by the majority of farmers as a favourable adaptation to reduce the risk, especially in drought conditions. Their prior consultation should make it possible to respond as well as possible to the specific needs of the different systems.

Finally, the production systems' vulnerability assessment makes it possible to distinguish different levels of robustness within the area. It appears that the systems for which agriculture is a secondary activity are more robust, which is certainly logical since the study focusses on agricultural vulnerability. However, the result could be different in the context of a broader study of the activity systems' vulnerability, i.e. taking into account the impact of external sociological and economic factors on household financial health. Thus non-agricultural incomes would no longer be as stable and robust as they are depicted in this study. The vulnerability of so-called « specialist » systems, which practice monoculture or the cultivation of a single agro-ecological zone, appears moderate. It should be specified that this degree is relative to the particular case studied, i.e. relative specialisation, since the production systems considered still cultivate diversity through the use of several spatially and temporally distant rice cropping systems or the combination of different crops on chamkar. It is clear that a system based on pure monoculture would be more vulnerable to climatic and other hazards. Within polyculture production systems, disparate levels of vulnerability are mainly based on the diversity of economic activities and the systems adaptive capacity. The SP3c production system appears to be highly vulnerable despite its good financial health and great crop diversity due to its total dependence on agricultural income and its determination to maintain crops that have been strongly affected by hazards in recent years.

Outlook

Agriculture in the prek area is exposed to flooding and drought, as are many Cambodian provinces (GSSD, 2015, World Bank, 2006, Eastham et al., 2008) and as are and will be many other parts of the world (IPCC, 2018, Miyan, 2015). The agrarian system analysis, by identifying the local agricultural diversity, allowed the realization of a vulnerability study at the production systems scale. This approach is rather original, since vulnerability studies are generally based on different scales (household, commune, watershed, region) (Doch et al., 2015, Turner et al., 2003, Cheb Hoeurn, 2013). Therefore this study provides a detailed agricultural analysis and allows the results to be generalised by categorising households, but has the disadvantage of not integrating the response mechanisms occurring at higher scales. Rural development policies in particular should be able to reduce the vulnerability of agriculture by limiting its exposure to hazards. In the prek region, the production systems adaptation is reflected in changes in agricultural practices (diversification, crops less sensitive to hazards, irrigation management, etc.) and activities (income diversification, marketing, product processing, etc.). Besides, rehabilitation projects may support this adaptation through the development of infrastructures in order to reduce exposure to hazards (improving water availability against drought, gates and drainage management to control flood occurence, electrification to reduce pumping costs, etc.). This study may be seen as a method basis for assessing the agricultural vulnerability to hydrological hazards. To go further, future works should integrate complementary data useful for drought impact modelling and identify more specifically flood exposure trough remote sensing analysis. Finally, increasing the size of the survey sample should make it possible to spatialize vulnerability and assess the influence of hydraulic developments on vulnerability.

References

Allen, R.G., Pereira, L., Dirk, R., Smith, M., 1998. Crop Evapotranspiration. FAO Irrigation and Drainage Paper 56, 327.

Anderies, J.M., Janssen, M.A., Ostrom, E., 2004. A Framework to Analyze the Robustness of Social-ecological Systems from an Institutional Perspective. Ecology & Society 9, art18. https://doi.org/10.5751/ES-00610-090118

Barthélémy, R., 1909. Hydraulique agricole-Les canaux de colmatage. Archives nationales du Cambodge, Phnom Penh (accessed February 2020).

Baume, J.P, Belaud, G., Vion, P.Y, 2013. Hydraulique pour le génie rural. https://hydraulique.g-eau.fr/-Hydraulique-pour-le-genie-rural-

Brouwer C., Heibloem M.,1986. « FAO Irrigation water management : training manual n°3 ». http://www.fao.org/3/s2022e/s2022e00.htm. (accessed March 2020).

Cheb H., 2013. Rural Households' Vulnerability Assessment to Climate Variability The Case of Peang Lvea Commune, Odongk District, Kampong Speu Province, Cambodia (Working Paper No. 1), Research Working Paper Series. Mekong Institute.

Cochet, H., 2011. Origine et actualité du «Système Agraire»: retour sur un concept. Revue Tiers Monde 207, 97. https://doi.org/10.3917/rtm.207.0097

Cosslett, T.L., Cosslett, P.D., 2018. Sustainable Development of Rice and Water Resources in Mainland Southeast Asia and Mekong River Basin. Springer Singapore, Singapore. https://doi.org/10.1007/978-981-10-5613-0

Deligne, A., 2013. Réseaux sociotechniques et politiques de gestion des systèmes irrigués au Cambodge.

Doch, S., Diepart, J.-C., HENG Chinda, 2015. A multi-scale flood vulnerability assessment of agricultural production A in the context of environmental change: The case of the Sangkae River watershed, Battambang province 32.

Doorenbos, J., Kassam, A.H., Bentvelsen, C., Uittenbogaard, G., 1980. Yield Response to Water, in: Irrigation and Agricultural Development. Elsevier, pp. 257–280.

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G., Ali, R., Kirby, M., 2008. Mekong River Basin water resources assessment: impacts of climate change, CSIRO: Water for a Healthy Country National Research Flagship.

General Secretariat, National Council for Sustainable Development/Ministry of Environment, Kingdom of Cambodia, Phnom Penh., 2015. Cambodia's Second National Communication under the United Nations Framework Convention on Climate Change.

Hecht, J.S., Lacombe, G., Arias, M.E., Dang, T.D., Piman, T., 2019. Hydropower dams of the Mekong River basin: A review of their hydrological impacts. Journal of Hydrology 568, 285–300. https://doi.org/10.1016/j.jhydrol.2018.10.045

IPCC, 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

Keskinen, M., 2006. The Lake with Floating Villages: Socio-economic Analysis of the Tonle Sap Lake. International Journal of Water Resources Development 22, 463–480. https://doi.org/10.1080/07900620500482568

Mazoyer, M., Roudard, L., 1997. Histoire des agricultures du monde. Du néolithique à la crise contemporaine, Seuil. ed, p.46.

McCarthy, J.J., Intergovernmental Panel on Climate Change (Eds.), 2001. Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK; New York.

Mekong River Comission hydrological stations data, n.d. URL http://ffw.mrcmekong.org/hydro_graph.php?StCode=KOH&StName=Koh+Khel+%28Bassac%29 (accessed April 2020).

Mekong River Commission, 2019. Enhancement of Basin-wide Flood Analysis and Additional Simulations under Climate Change for Impact Assessment and MASAP Preparation, p. 52.

Mekong River Comission, n.d. Mekong basin physiography [WWW Document]. Mekong River Comission for sustainable development. URL http://www.mrcmekong.org/mekong-basin/physiography/ (accessed April 2020).

Morel, N., 1996. Analyse-diagnostic du système agraire de berge au Cambodge.

Miyan, M.A., 2015. Droughts in Asian Least Developed Countries: Vulnerability and sustainability. Weather and Climate Extremes 7, 8–23.

National Institute of Statistics, 2015. Census of Agriculture of the Kingdom of Cambodia.

Pacific Rim Innovation and Management Exponents, 2019. National Water Resources Data Management Center and Water Resources Information System Report.

SOFRECO, 2017. Water & Agriculture Sector Programme (WASP) – Package 2. « Technical Assistance for the implementation of Preks of Kandal Component (TA-Preks), final report ».

Steduto, P., Food and Agriculture Organization of the United Nations (Eds.), 2012. Crop yield response to water, FAO irrigation and drainage paper. Food and Agriculture Organization of the United Nations, Rome.

The World Bank, 2006. Managing Risk and Vulnerability in Cambodia: An Assessment and Strategy for Social Protection (No. 38209). Cambodia.

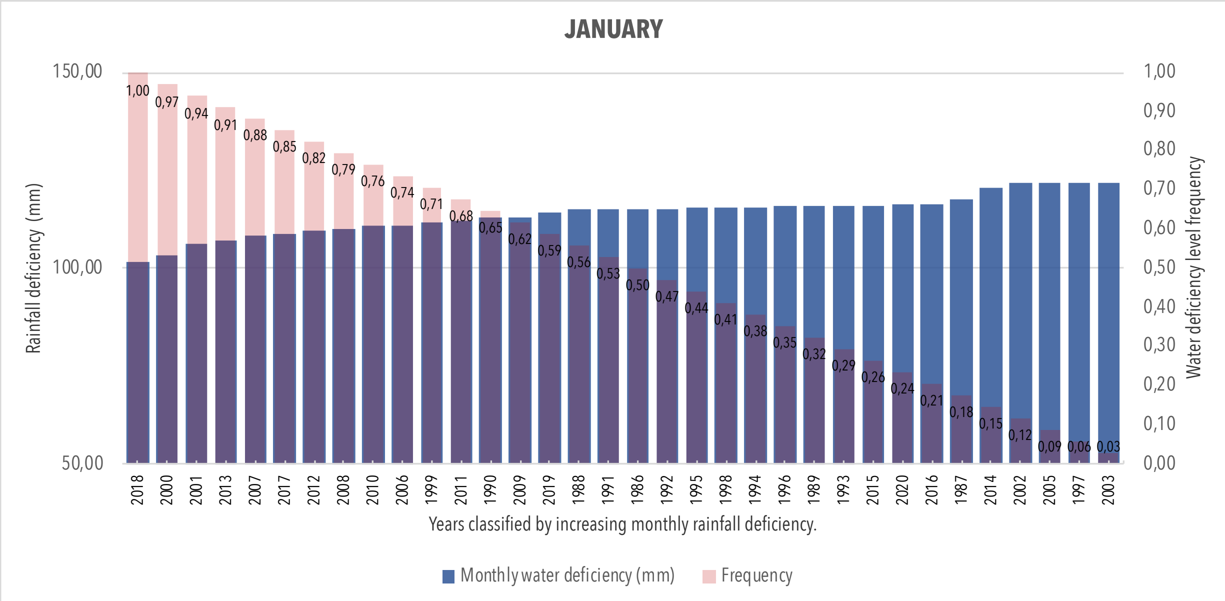
Vandôme, P., Pinta, J., Orieschnig, C., Belaud, G., 2020. Impacts of flood variability on rice cultivation in the prek agricultural systems of the upper Mekong delta, Cambodia. Revue eau et agriculture, MSc Eau et Agriculture, Montpellier.

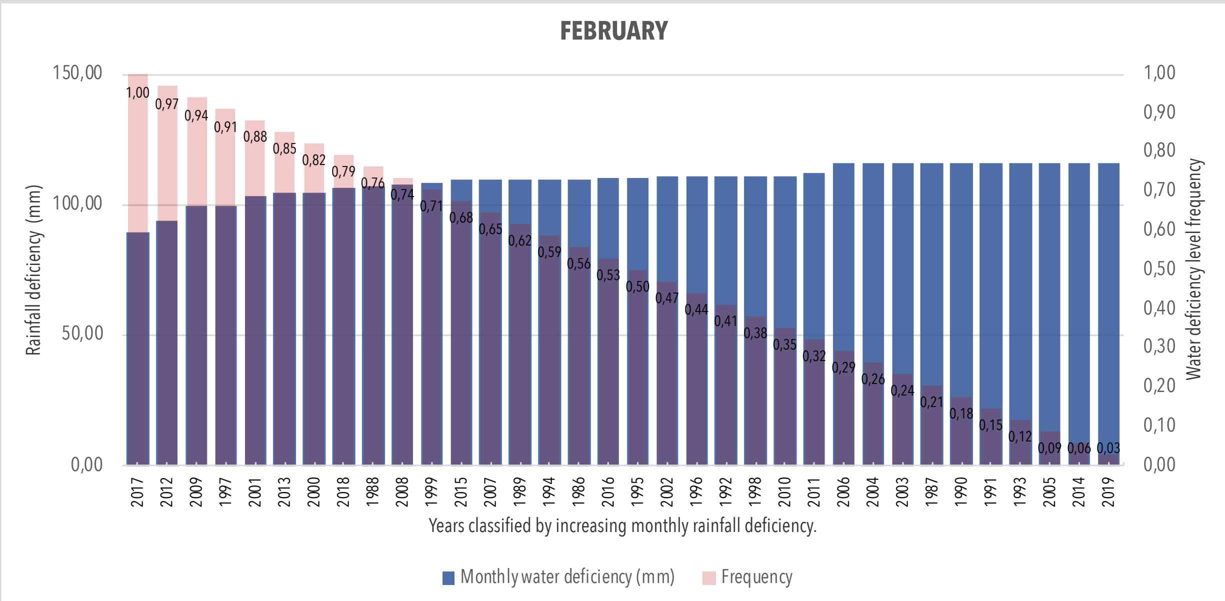
Yang, J., Yang, Y.C.E., Chang, J., Zhang, J., Yao, J., 2019. Impact of dam development and climate change on hydroecological conditions and natural hazard risk in the Mekong River Basin. Journal of Hydrology 579, 124177. https://doi.org/10.1016/j.jhydrol.2019.124177

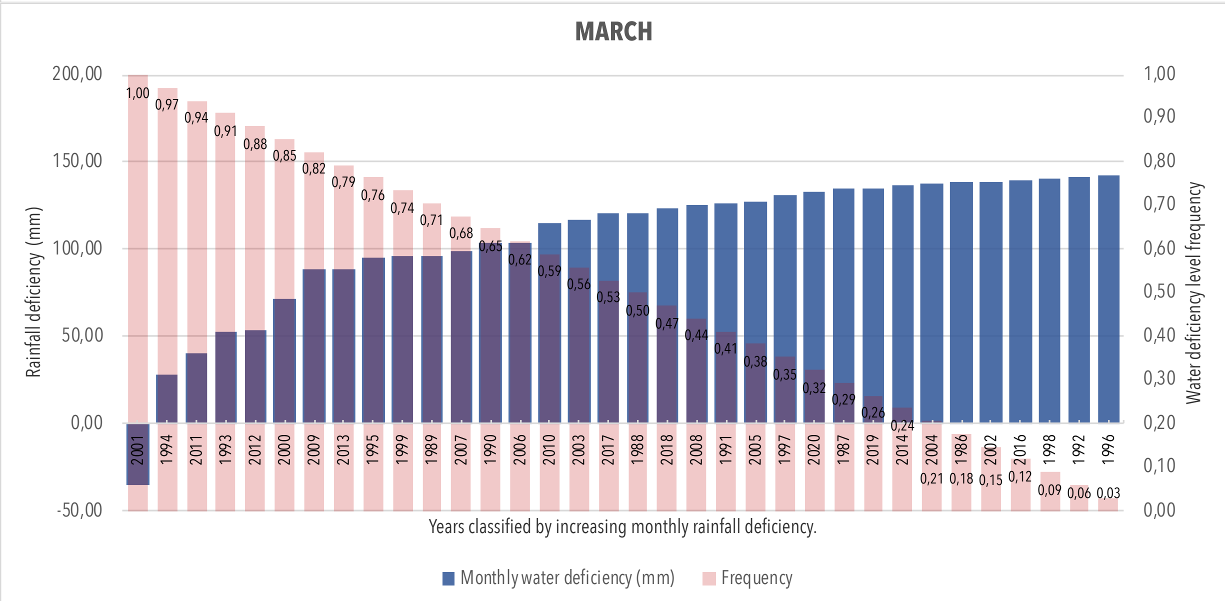
What is drought? Understanding and defining drought. [WWW Document], 2006. . National Drought Mitigation Center (NDMC). URL https://drought.unl.edu/Education/DroughtIn-depth/WhatisDrought.aspx (accessed 4.15.20).

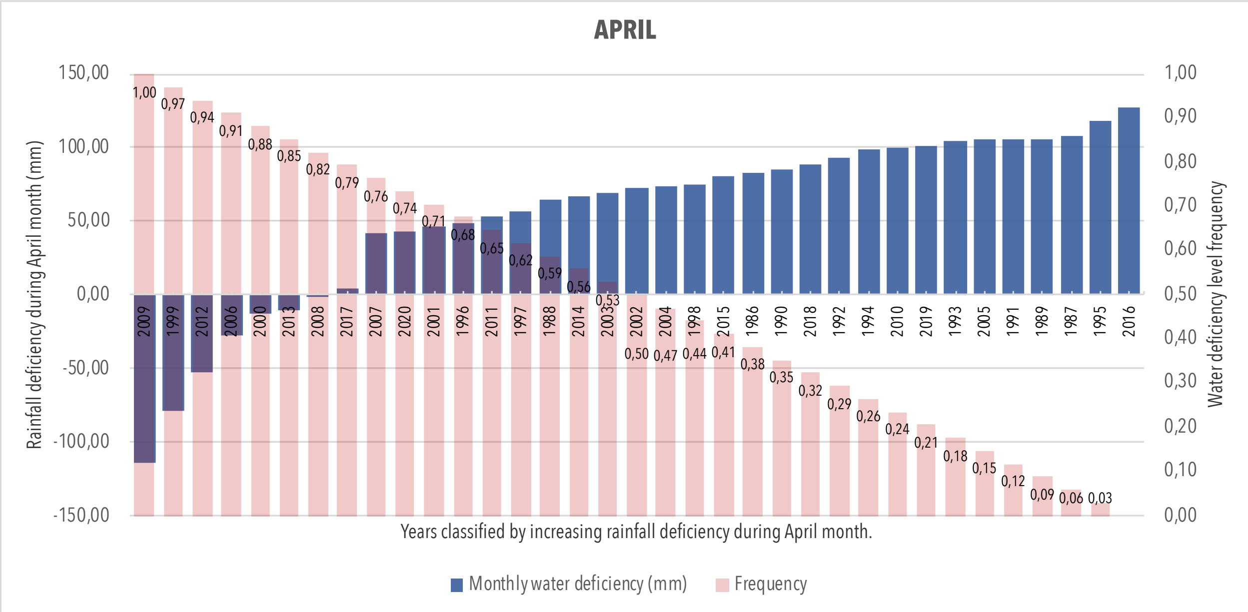
List of annexes

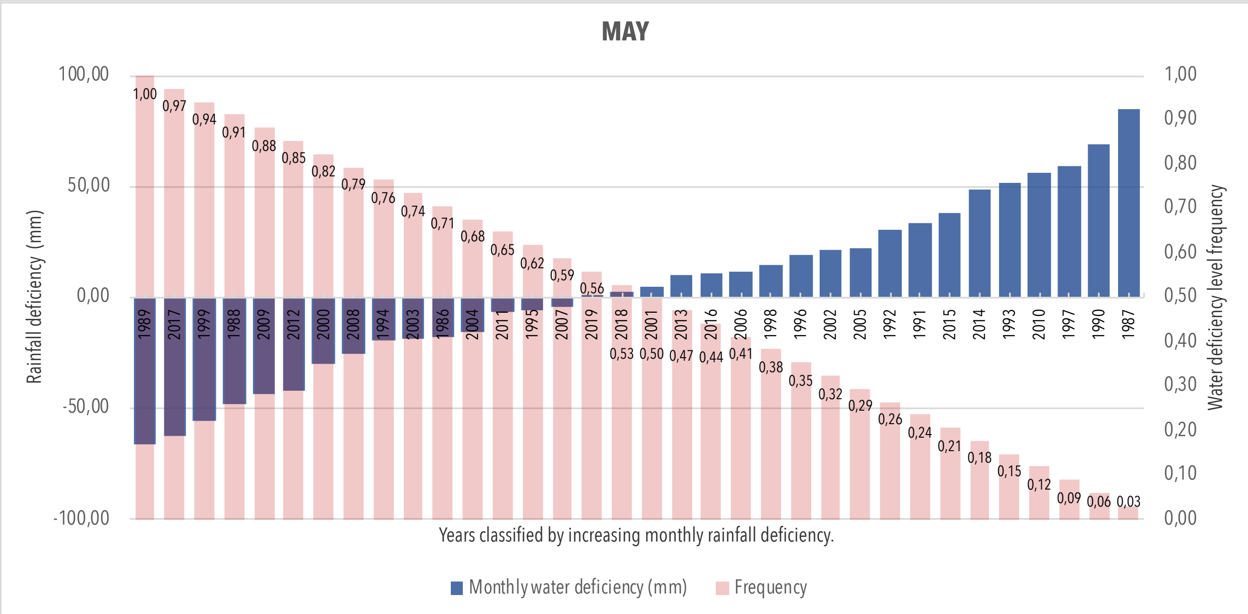
Annex A - Frequency analysis of the monthly rainfall deficit in the study area from the CHIRPS 1986 - 2019 time series.

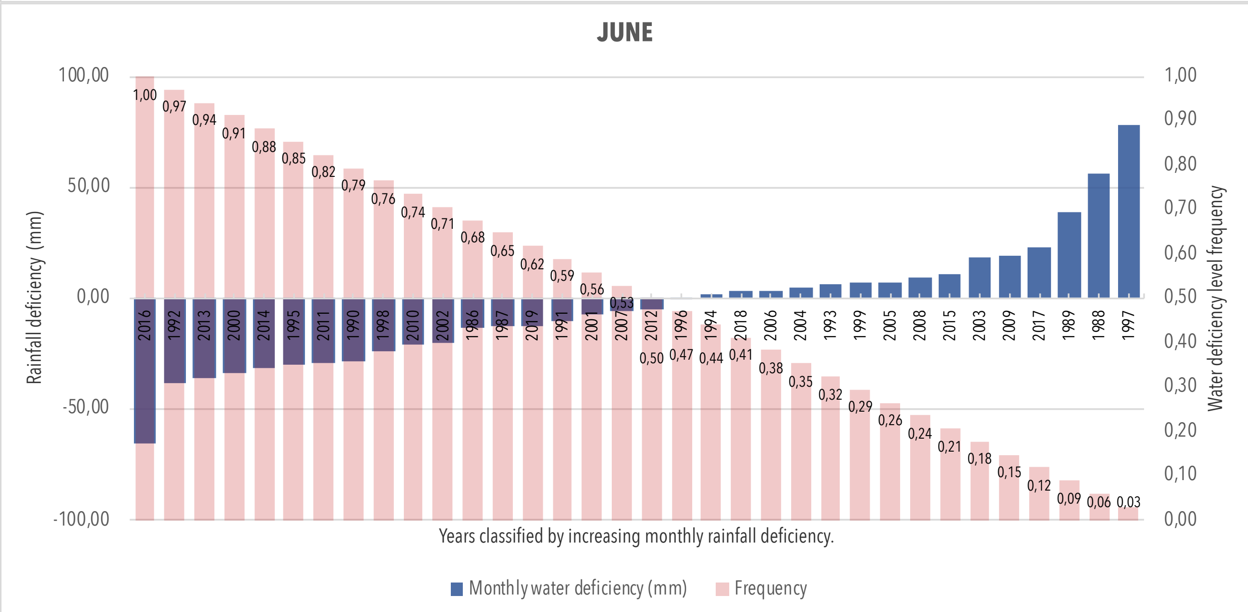


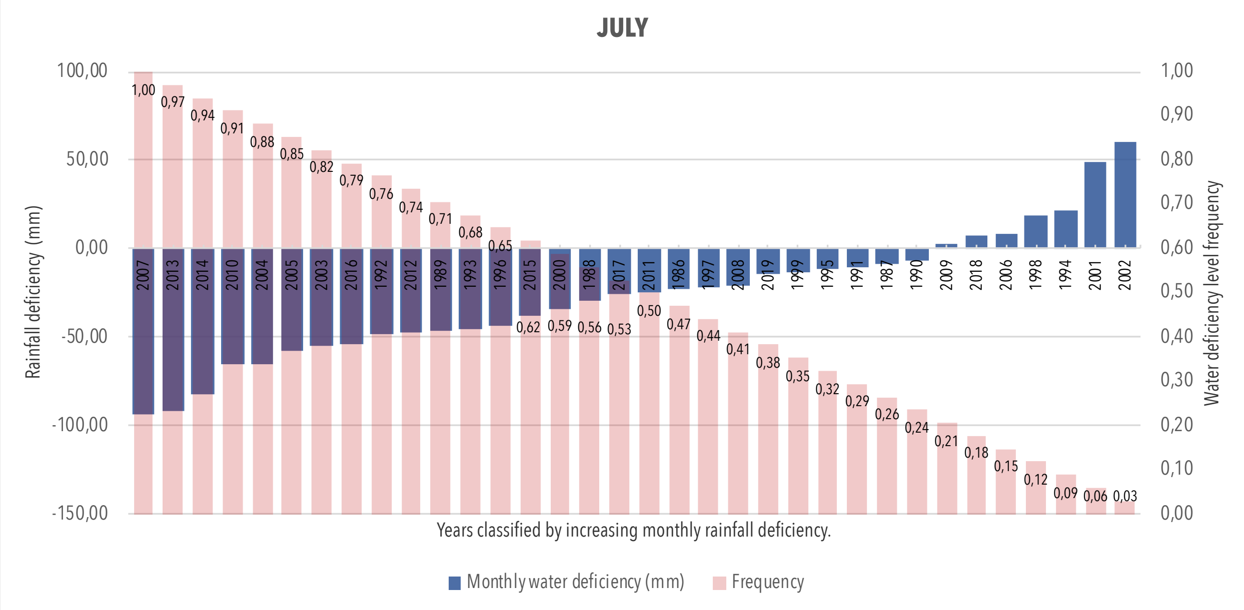


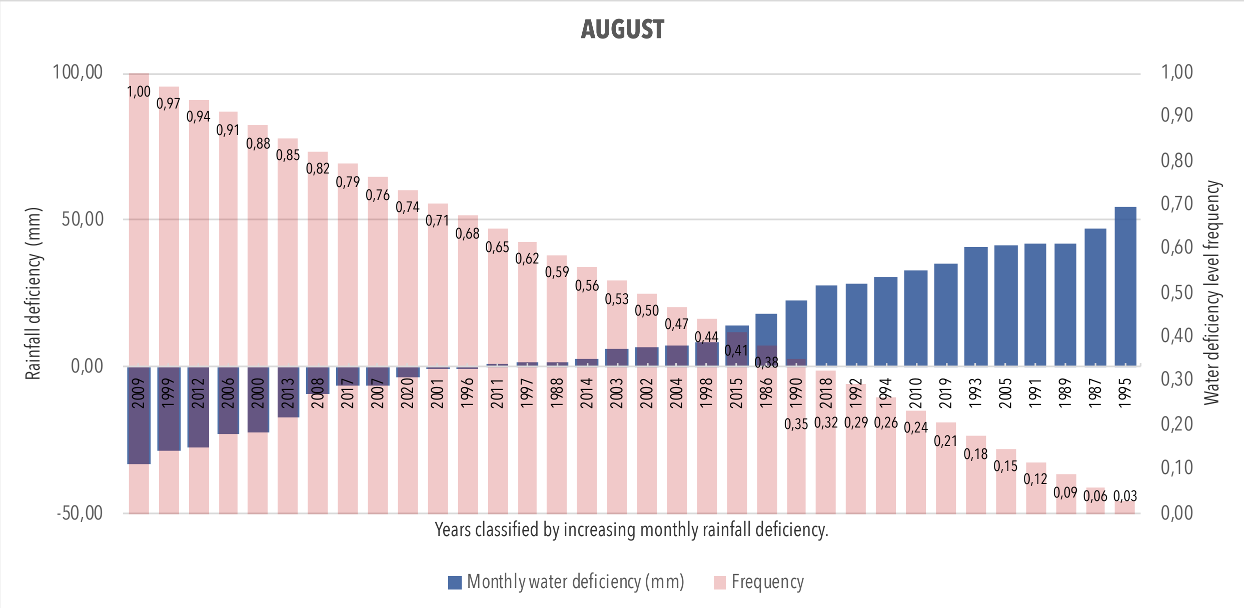


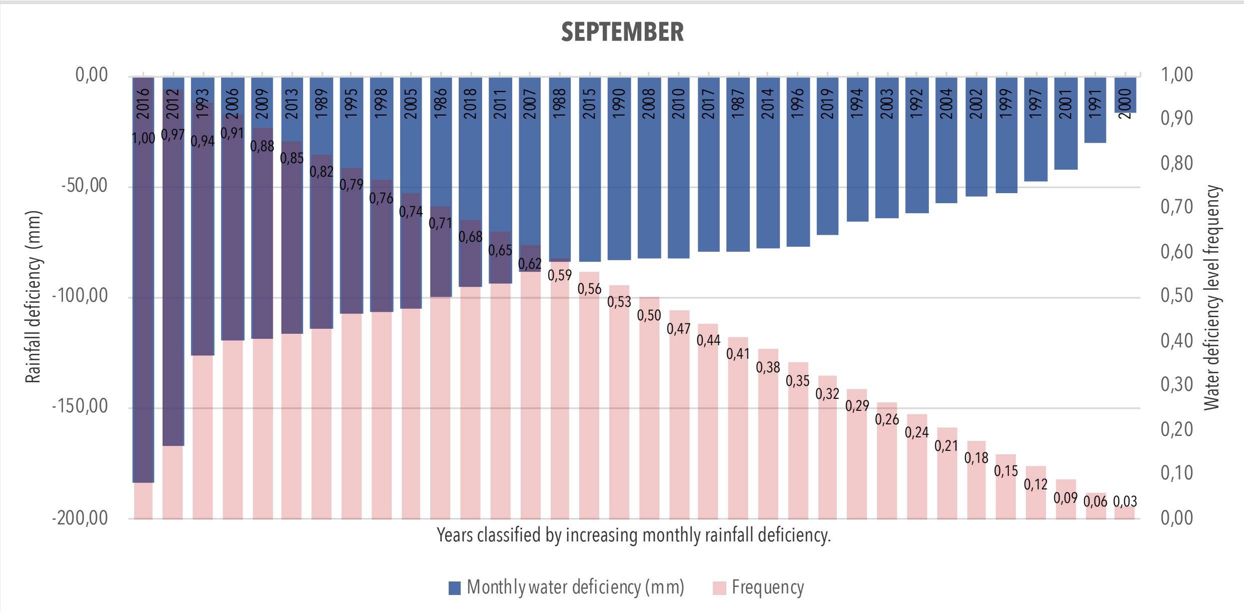

APRIL
Rainfall deficiency during April month (mm)
Water deficiency level frequency
Years classified by increasing rainfall deficiency during April month.
Monthly water deficiency (mm)
Frequency

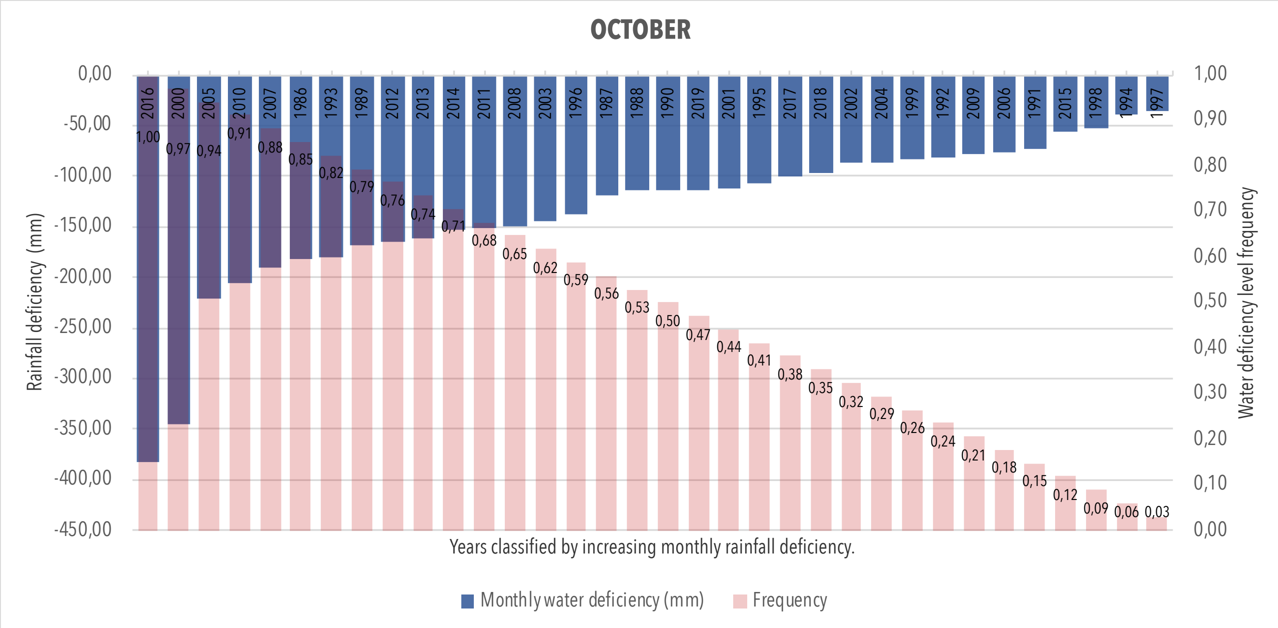

MAY
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency

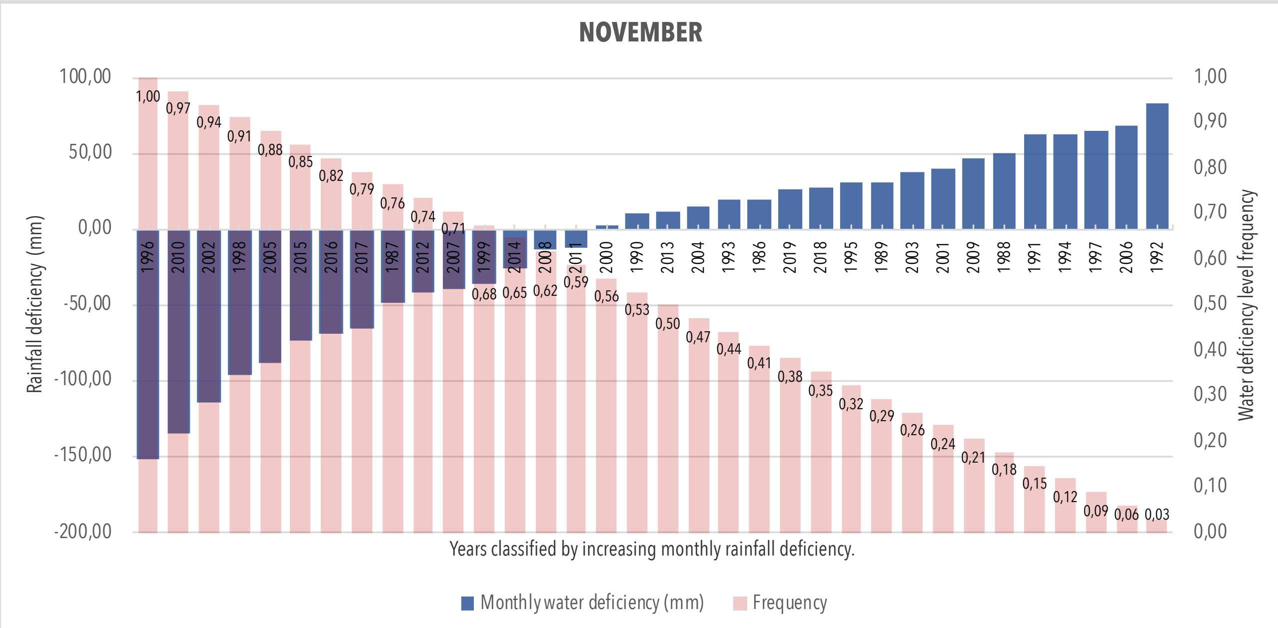

JUNE
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency

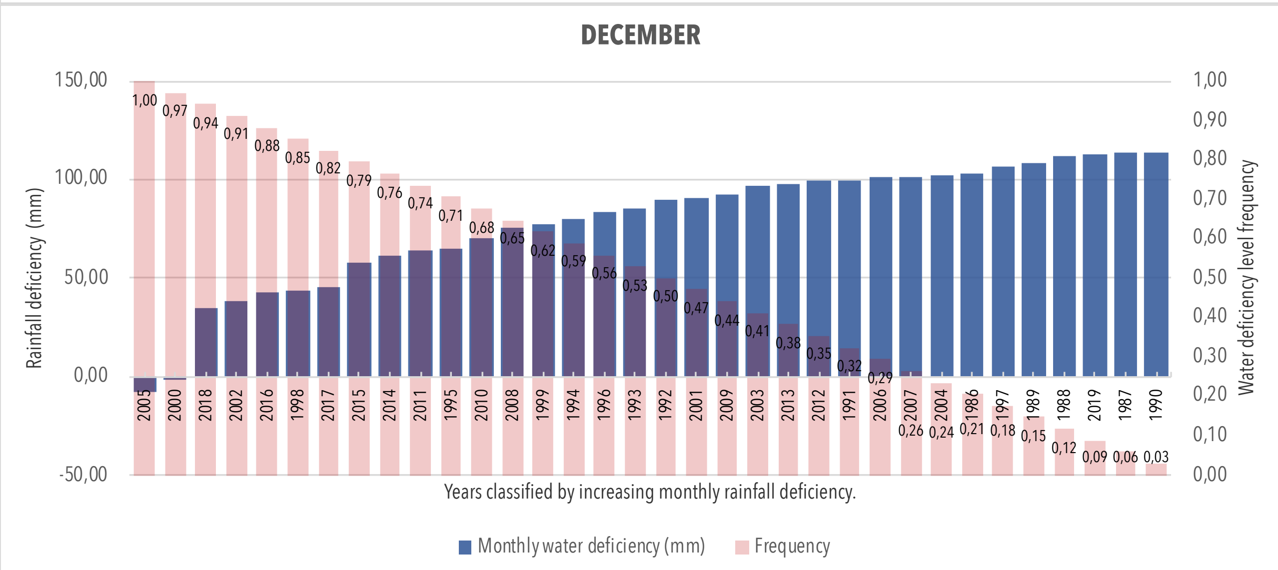

JULY
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency


AUGUST
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency


SEPTEMBER
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency


OCTOBER
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency


NOVEMBER
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency


DECEMBER
Rainfall deficiency (mm)
Water deficiency level frequency
Years classified by increasing monthly rainfall deficiency.
Monthly water deficiency (mm)
Frequency

Questionnaire Farmers | Interview Nr: __________ Date: __________ Prek: _________

Primary aims: finding out details about crop rotation, irrigation schedule (pumping), well pumping, rationale of decision making, fishing and other livelihoods activities and strategies

Name: ______________________ Gender: ______________________

Age : ______________________ Village/Commune: ______________________

Telephone number: ______________________

Please tick relevant sources of income:

- [ ] Agricultural income
- [ ] Livestock rearing
- [ ] Fishing
- [ ] Palm juice/sugar production
- [ ] Small Business
- [ ] Non agricultural incomes
- [ ] Agricultural wage labor
- [ ] Remittance from family member

1 of 13

Part A: Agriculture & Economics

Fill out crop table (A3)

How many **pumps** do you own?

- How big are they (HP)
- Do you move them between plots? If yes, how often do you move them?

If they have a **well** that is not (only) used for irrigation:

- What do you use the water of the well for?
- How often/for how long do you pump water from the well?
- How much fuel do you use per hour of pumping?

Do you own **farm equipment** ?

- If so, what do you own ?

☐ Moto-tiller
☐ Pump
☐ Other :
☐ Sprayer
☐ Plough

- If not, do you rent it ? From whom and for how much ?

Fishing

Do you fish ?

Is the fishing **for your own use or to sell the catch**?

Fishing	Notes/Details	N	D	J	F	M	A	M	J	J	A	S	O
		I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I	I II II I
Boeung													
Canal													
Prek													
Fishing implements													
Average catch (kg per fishing time)													
Fishing times per week?													

When are the **peak fishing periods**?

- Are these periods linked to any weather/climate conditions?
- Is fish catch affected by the tide?
- Is fish catch affected by the moon phases?

Livestock

- Do you have **livestock** ? If so, how many heads ? For what production (milk, meat) ?

- How do you feed your cattle (rice straw/natural vegetation/fodder) ?

- If fodder is purchased, what is the cost of a bag ? How many bags do you buy in a year/season ?

- Do you use the manure ? What for (fertilizing, selling) ?

Do you breed/fatten **pigs**?

- How many?
- How do you feed them?

Do you keep **ducks**? Or do you let duck-farmers graze their animals on your plots?

- How many ducks graze on your plots?
- What is the benefit for you?

Economics

- Do you contract a **loan** in the course of your **farming** activity? If so, what for, and under what conditions (bank, usurer, interest rate) ?

- Do you have **any other long term or short term loan** ? If so, what for, and under what conditions (interest rate) ?

- Could you give precise income for each activity (USD or ៛).

Activities	Livestock	Fishing	Small business	Salary from workplace	Pension fund	Agricultural wage labor
Incomes						
Activities	Motor taxi	Construction worker	Garment worker	Remittance from relatives	Other (specify)	
Incomes						

- What is the share of your farm income in your total income ? (check if it seems logical)

Decision Making

Can you explain, what do you generally take into account to take the **decision to irrigate**? (neighbours, regular schedule, soil moisture, precipitation, water level in Bassac / Prek?)

Can you explain, what do you take into account to take the **decision to plant your crops**? (neighbours, regular schedule, soil moisture, precipitation, water level in Bassac / Prek?)

Crop	Decision to plant	Decision to irrigate

Part B - Agricultural risk and adaptation capacity

Agricultural risk

- Over the last three years, have you **lost crops due to floods** ? Where and when ? Can you quantify the loss (% area, %yield, revenue loss) ?

Year	Crop	Where in your plots?	Loss (Y/N)	Area %	Yield %	Revenue (%)	Date of arrival of the flood	Water level (cm) in field

- Over the last three years, have you **lost crops due to droughts** ? Where and when ? Can you quantify the loss (% area, %yield, revenue loss) ?

Year	Crop	Where in your plots?	Loss (Y/N)	Area %	Yield %	Revenue (%)	Date of loss

Agricultural risk

- Have you lost crops due to **pests**?

If yes, can you estimate how much **[%] you have lost** because of pests?

Which pests affect your plots?

How can they be **controlled**?

Does the **flood also help to control pests** (rats) ?

How long does the flood have to last to get rid of rats? How high does the water have to be?

Does the **speed of the water level increase** has an impact (e.g. rats are killed more efficiently if the water rises fast).

Adaptation Capacity

Do you have **strategies to avoid crop losses due to flooding** (land and water management, sowing dates, crop location, resistant varieties…) ?

Do you have **strategies to avoid crop losses due to drought** (irrigation system, sowing dates, crop location, resistant varieties…) ?

Do you think the **Prek rehabilitation provides an opportunity to decrease the risk of floods** ? How does it protect ?

Do you think the **Prek rehabilitation provides an opportunity to decrease the risk of droughts** ? How does it protect ?

Have you **changed varieties or crops during the past 5 years**? Why (market, water availability, reduce D/F risks, ease of cultivation, rehabilitation) ?

Do you plan **changes in varieties or crops in the coming years** ? Why (market, water availability, reduce D/F risks, ease of cultivation, rehabilitation) ?

Do you plan **new agricultural investments** (pump, tiller, land, fruit trees…) ? If not, why ?

Have you been **impacted by the short duration of the flood last season?** How ? What have you done to deal with the situation ?

Have you been **impacted by the delay of the flood last season**? How ? What have you done to deal with the situation ?

Part C: General Operation and Uses of the Prek

Has the Prek next to your plots been **rehabilitated**?

Is there a **gate** at this Prek?

- What is the purpose of the gate?
    - Is it useful to slow down/avoid floods or to keep water in the Prek?
    - If not: why not?
- Are you involved in deciding when the gate is being opened/closed?

Is there a **Prek User Community** at this Prek?

- What are the main tasks of the PUC?
- Are you involved in the PUC?
- Does the PUC coordinate who gets to pump water at which times?

Before rehabilitation, was someone **operating a pump to supply the Prek** with water?

- Who was it?
- What happened to his pumping business?

Is there (still) any **time** of the year **when water needs to be pumped into the Prek**?

- If yes: From where is it pumped: the Bassac or the canals in the floodplain?
- Who is responsible for it?
  - Name
  - Phone number

Who builds **earthen dams** across the Prek?

- What are they for?
- Does someone coordinate the building?
- What happens to the farmers who don't get water because it is kept in one part of the Prek by the dams?

Do you use the Preks for **transport**?

Do you have a **boat**?

What do you use it **for**?

- Do you use it for your own purpose?
- Do you use it to transport and sell goods for other farmers?

During which months do you use it?

Where do you use it? (Prek/Boeung?)

Do you use the **natural vegetation** that grows along the Prek?

If yes, **what** do you use it **for**?

- ☐ Fuel
- ☐ Construction material
- ☐ Food
- ☐ Fish traps
- ☐ Animal feeding
- ☐ Other :

Where do you find the vegetation that you use in that way?

BASIC INFORMATION	
Interview code	
Prek	
How many plots do you have	
Could you show/lead me to your plots ?	
Annex info	

Crop&losses	Irrigation	Production costs	Incomes	Irrigation system
Variety	Irrigation source	Labor force (USD/man/day)	For sale/for living	Equipment on the plot
Production [kg]	Irrigation frequency	Pesticides (USD/crop/application)	Product destination	
Crop/yield losses ? (Y/N)	Pumping time [h]	Fertilizers (qtity-USD/crop/application)	Unit price (riel/kg)	
Losses reason (D,F,other)	Pump characteristics : Q [m3/h] or HP	Pumping (diesel)		
Lost production/yield ? (%, kg)	If rice : water depth max-min (mm)	Seeds (USD/bag-USD/crop)		

CROPPING SYSTEM		Crop ID	Crop Type	A			S			O			N			D			J			F			M			A			M			J			J		
Plot	Area [ha]/Location	Practice type	Practice detail	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Plot 1		Crop 1																																					
		Irrigation																																					
		LP																																					
		Pesticides (H,I,R)																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
		Crop 2																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
Plot 2		Crop 1																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
		Crop 2																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
Plot 3		Crop 1																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
		Crop 2																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
Plot 4		Crop 1																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					
		Crop 2																																					
		Irrigation																																					
		LP																																					
		Pesticides																																					
		Fertilizers																																					
		Working days (day-man/month)																																					

Input seller interview

Village : Shop name : Seller name : Phone number :

- Which villages are served by this shop (is it in the prek area ?) ? Approximatively how many customers ?

- List the 5 products that you sell the most. For what crops ? For what purpose ?

Purpose (H, I, D, R)	Product	Crops

- For the following crops, what are your recommendations in terms of pesticides ? Purpose, quantity, price ?

Crops	Products and purpose (H, D, I, R) Precise if liquid.	Quantity recommended (bags or kg /ha or / application)	Price (usd/bag)
Rice			
Maize			
Mango			
Vegetables			

Annex D - Monthly climatic data from CLIMWAT software database, Phnom Penh-Pochentong station.

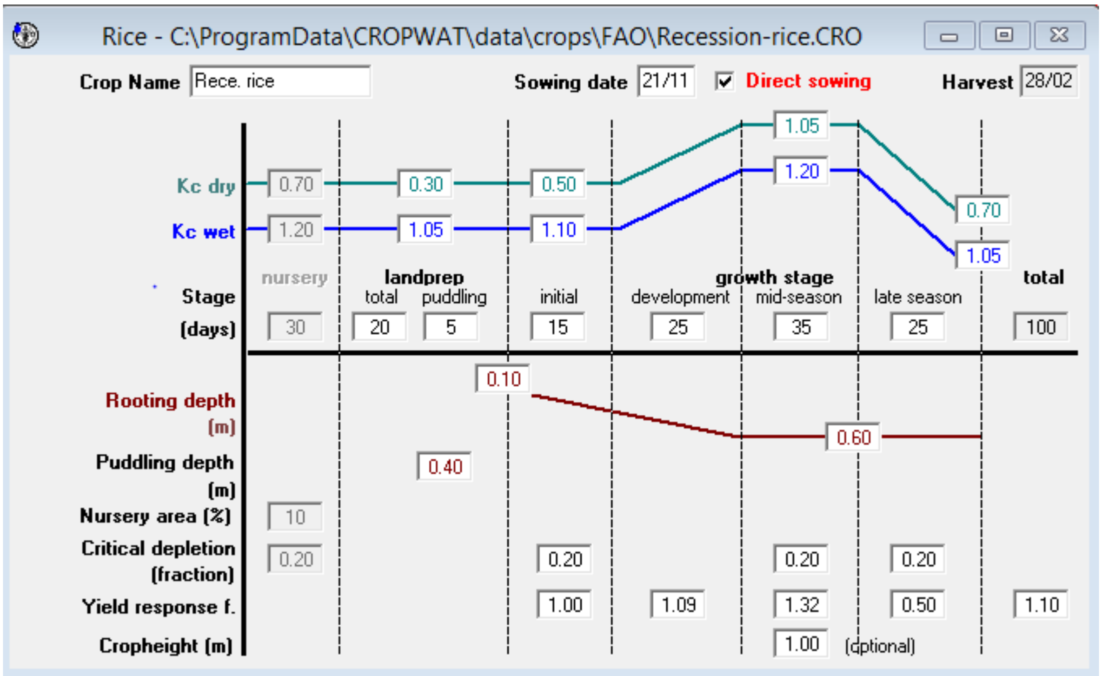
MONTHLY ETO PENMAN-MONTEITH DATA
(File: C:\ProgramData\CROPWAT\data\climate\PHNOM-PENH-POCHENTONG.pem)

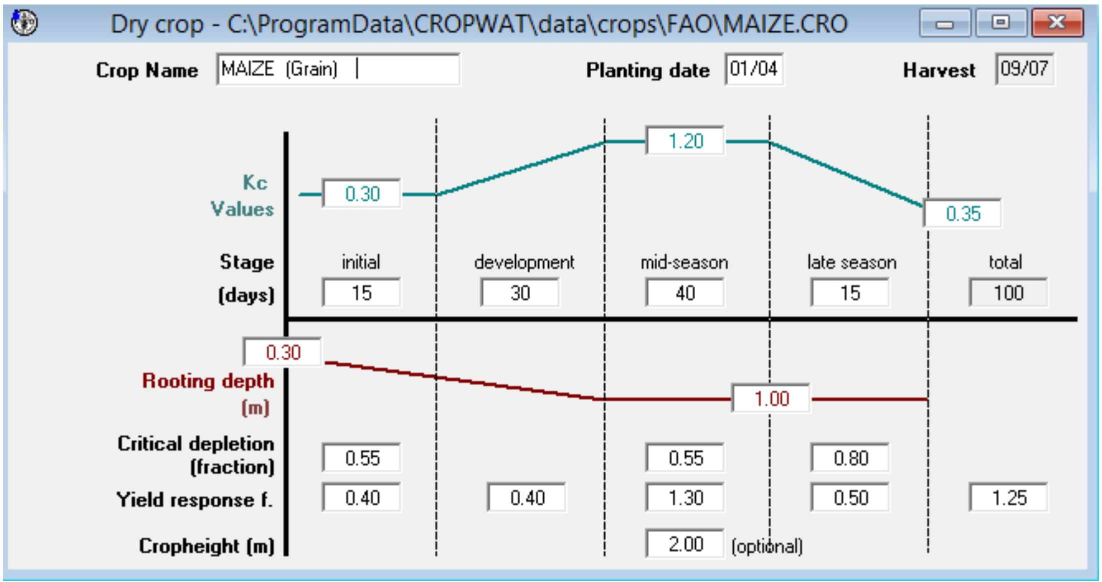
Country: Location 2
Altitude: 10 m.

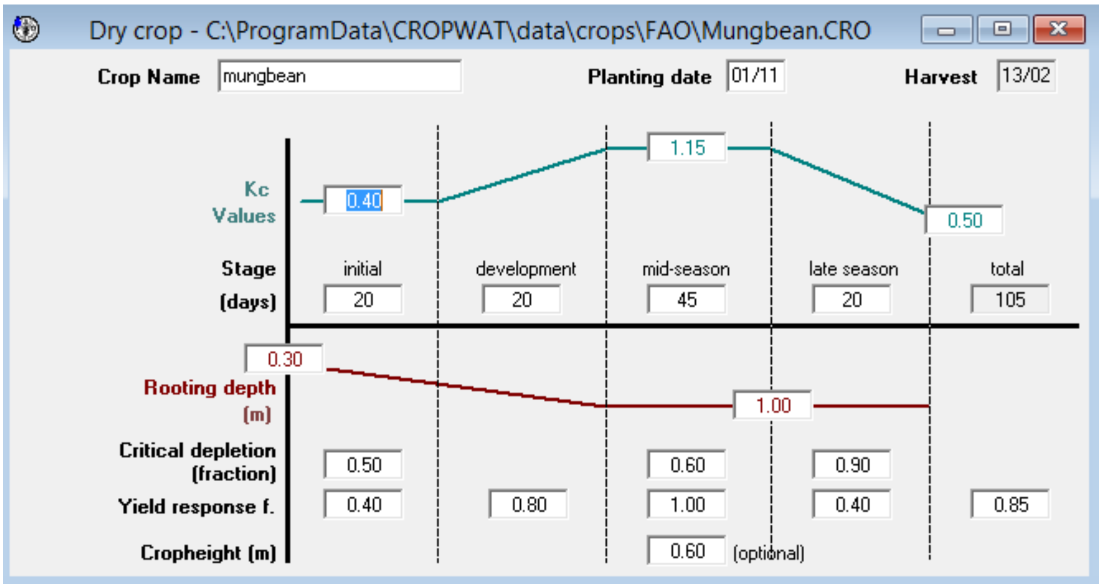
Station: PHNOM-PENH-POCHENTON
Latitude: 11.55 °N   Longitude: 104.85 °E

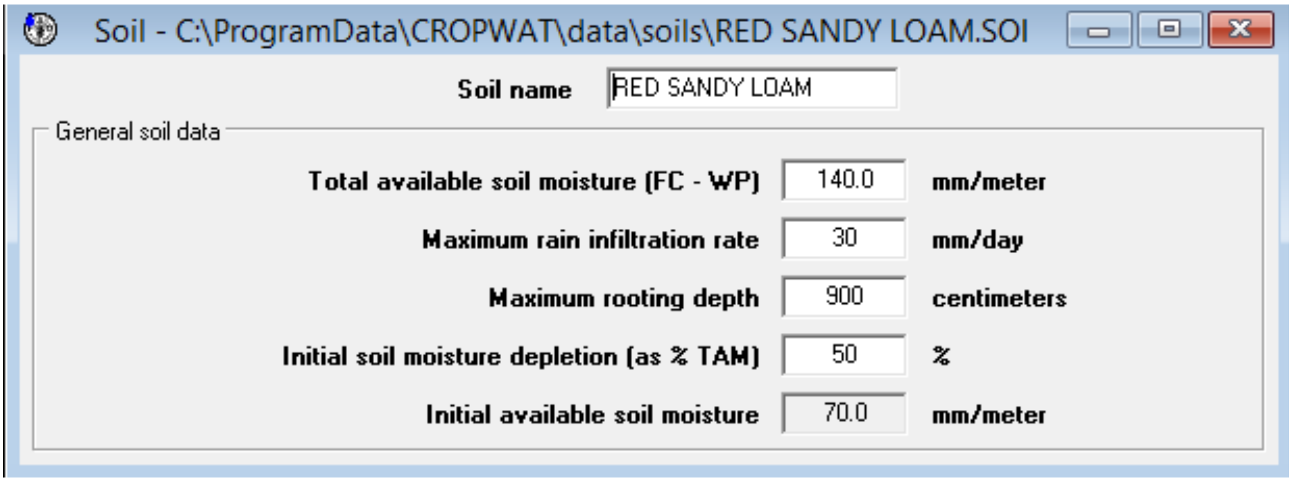
Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	21.3	30.7	68	104	7.9	18.7	3.93
February	22.0	32.1	64	78	7.6	19.6	4.15
March	23.2	33.6	61	86	8.2	21.7	4.83
April	24.3	34.6	66	78	7.7	21.4	4.88
May	24.3	33.5	77	86	6.4	19.1	4.36
June	24.3	32.7	77	61	6.3	18.7	4.12
July	24.1	31.6	78	86	4.8	16.5	3.76
August	24.7	31.7	80	78	5.7	18.1	3.99
September	24.7	30.9	82	78	4.5	16.2	3.58
October	24.4	30.4	81	61	6.4	18.1	3.78
November	23.3	30.1	77	86	6.9	17.5	3.66
December	21.8	30.0	72	104	7.4	17.4	3.66
Average	23.5	31.8	74	82	6.7	18.6	4.06

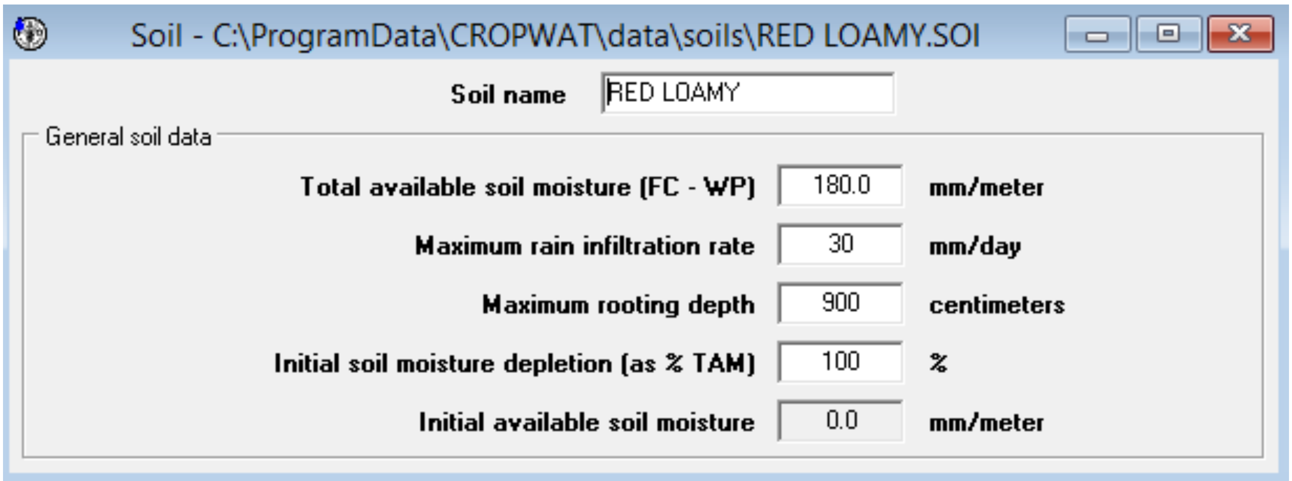
Annex E - Crop data input for CROPWAT modelling.

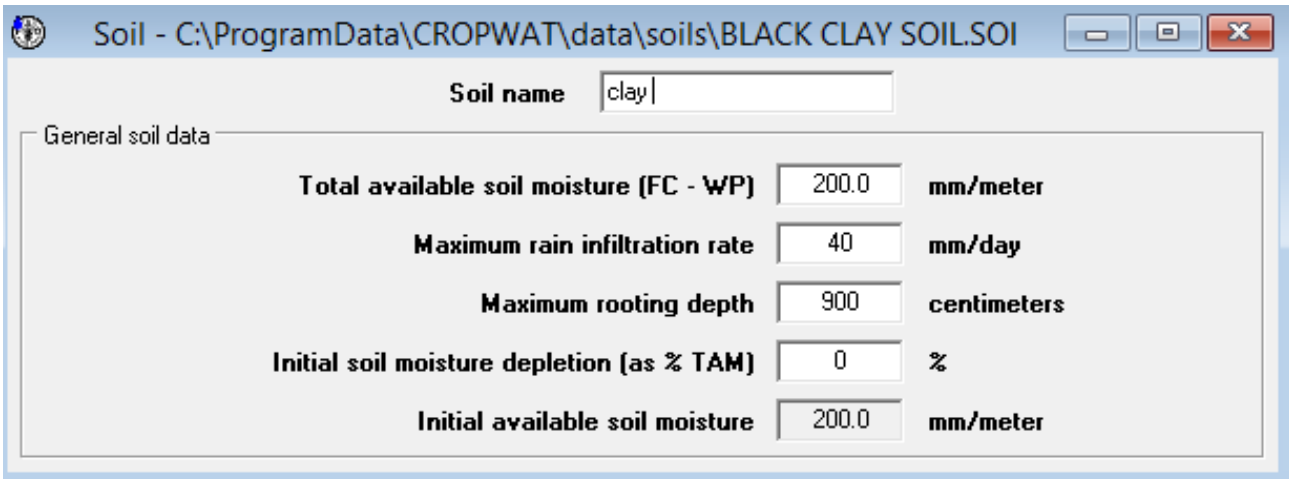




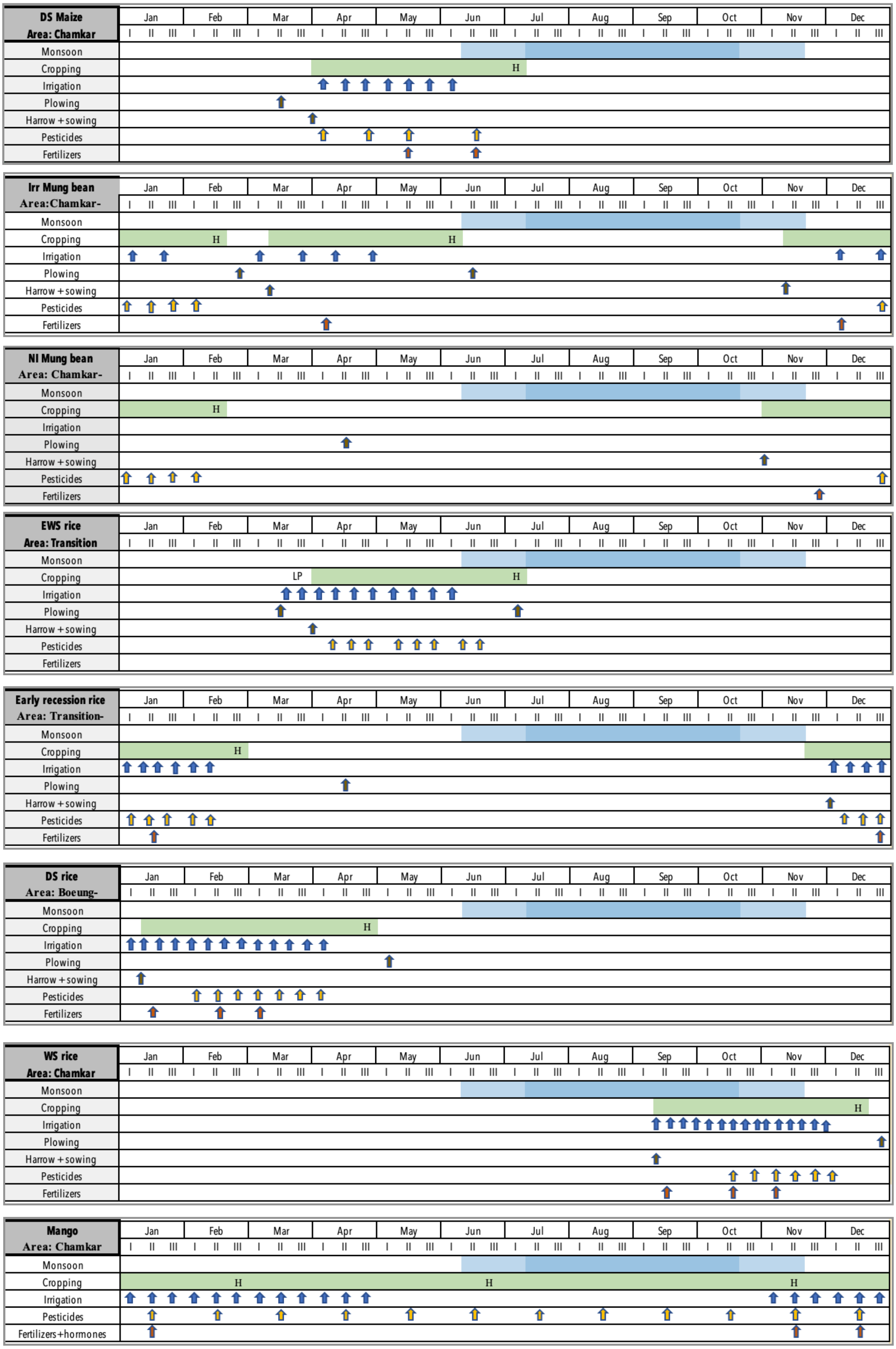



Soil - C:\ProgramData\CROPWAT\data\soils\RED SANDY LOAM.SOI
Soil name
RED SANDY LOAM
General soil data
Total available soil moisture (FC - WP)
140.0
mm/meter
Maximum rain infiltration rate
30
mm/day
Maximum rooting depth
900
centimeters
Initial soil moisture depletion (as % TAM)
50
%
Initial available soil moisture
70.0
mm/meter


Soil - C:\ProgramData\CROPWAT\data\soils\RED LOAMY.SOI
Soil name
RED LOAMY
General soil data
Total available soil moisture (FC - WP)
180.0
mm/meter
Maximum rain infiltration rate
30
mm/day
Maximum rooting depth
900
centimeters
Initial soil moisture depletion (as % TAM)
100
%
Initial available soil moisture
0.0
mm/meter

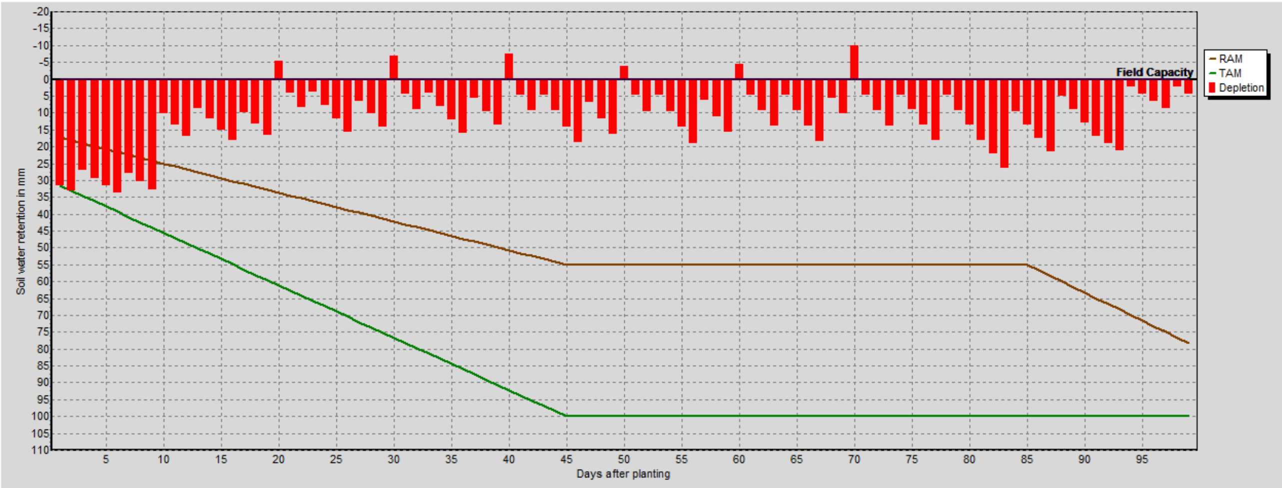

Soil - C:\ProgramData\CROPWAT\data\soils\BLACK CLAY SOIL.SOI
Soil name
clay
General soil data
Total available soil moisture (FC - WP)
200.0
mm/meter
Maximum rain infiltration rate
40
mm/day
Maximum rooting depth
900
centimeters
Initial soil moisture depletion (as % TAM)
0
%
Initial available soil moisture
200.0
mm/meter

Annex G - Main cropping systems' technical itineraries.

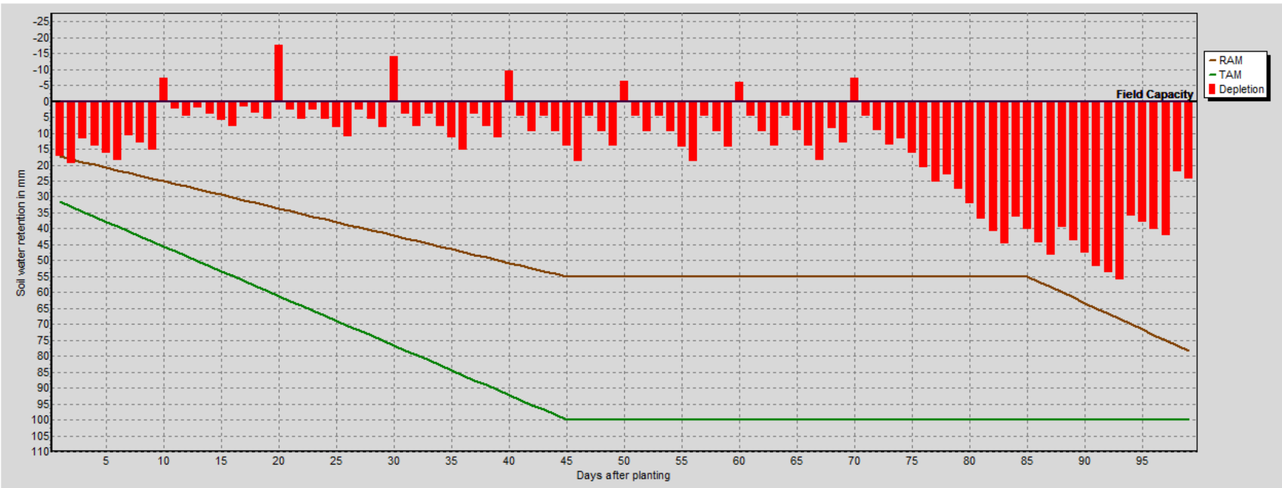


Annex H - Evolution of soil moisture depletion during maize cropping according to different hydrological scenarios.

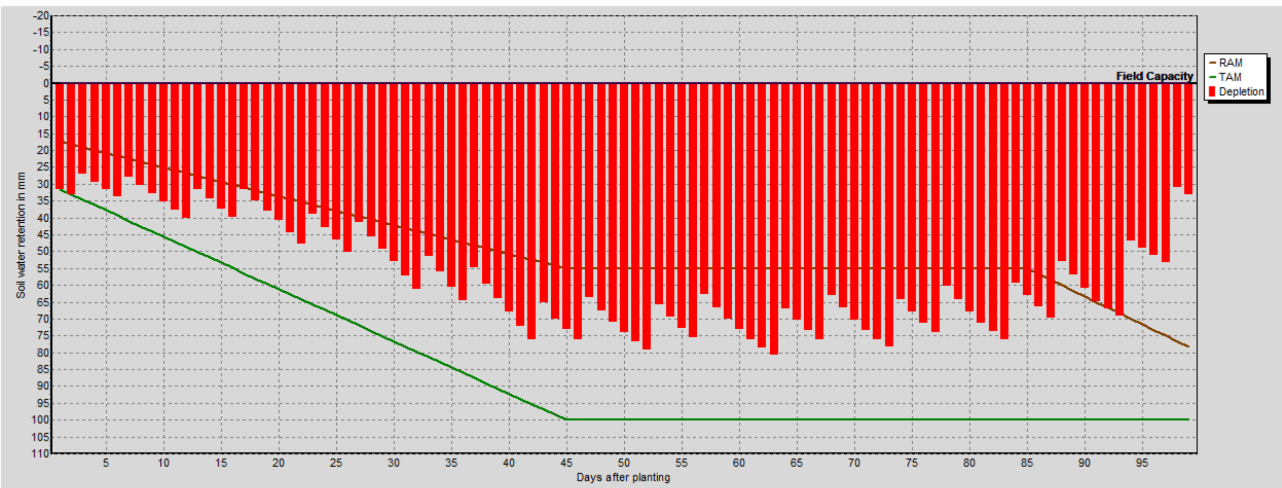
Control



5-years return rainfall deficiency



5-years return rainfall deficiency and no irrigation



Annex I - Decision tree for production systems' adaptation capacity.