INTERNSHIP REPORT

AGRICULTURAL LAND USE AND WATER REQUIREMENTS ON CAMBODIAN IRRIGATION SCHEMES : THE CASE OF PREKS

JULY - AUGUST 2019

VANDÔME Paul
paul.vandome@supagro.fr

Table of contents

Table of figures

Introduction

Deltaic plains are high-stake areas due to their soil fertility, ecological richness, high habitat densities and their function as « agricultural granaries ». Sensitive to hydrological and climatic hazards and anthropic pressures, delta areas are vulnerable and threatened. These regions are therefore of great importance, but also very fragile. Therefore, it is essential to develop a clear understanding of the hydrological functioning of these complex hydro-socio-ecosystems.

In Cambodia, in the upper Mekong delta between Phnom Penh and the Vietnamese border, life is governed by the hydrological regime of rivers, which imposes cropping schedules, navigation periods, life cycles within ecosystems etc. On both sides of the Mekong and the Bassac, the floodplain is crossed perpendicularly by old interconnected canals called preks. Designed under the French protectorate, their primary function was to supply sediment to the low lands of the rivers concerned. Faced with current challenges and constraints, preks are the subject of rehabilitation plans as part of a large national rural development programme, with the investment of several international donors such as the French Development Agency (AFD) and the Australian (AusAid), Japanese (JICA) and Chinese cooperation agencies. To respond to new water resource uses, climatic variations and the deteriorated state of infrastructures, rehabilitation plans promise better management for increasing water availability in space and time.

The G-eau research unit and the IRD (French National Research Institute for Sustainable Development) are invested in this region through various research programmes, including the PhD « Understanding Delta Hydrology from an Integrated Perspective - Hydrological Modelling of the Mekong Delta, Cambodia » prepared by Christina Orieschnig. The work carried out during this internship is part of this doctoral program, with the objective of characterizing the relationships between the water cycle and agricultural practices within the study area. Advances produced at the end of summer 2019 will serve as a first step towards continuing the project in the form of a scientific production and MSc. thesis during the academic year 2019-2020.

1. Context

1. Irrigated agriculture in Cambodia

Agriculture has always been a core element of Cambodian life. Irrigation infrastructure - reservoirs, canals, hydraulic facilities - have been widely used since ancient times. Today, about 80% of Cambodia's population live in rural areas and more than 70% depend directly on agricultural production for their livelihood (Agricultural Census, 2013). The continued development of the agricultural sector remains an important part of the government's strategy to reduce poverty in rural communities, achieve food security and implement an equitable and sustainable social development.

According to the Agricultural Census, there were 1.876 million of agricultural holdings growing crops in 2013, over a total area of 3.1 million ha. Around 75% of the production is used as subsistence farming, with the rest for sale. An agricultural holding is on average 1.75 ha. The biggest areas of agricultural lands are reported in the Tonle Sap (around 50%) and Mekong Delta (25%) river basin groups. Major annual crops reported are paddy rice (85% of the annual food crop production), corn, cassava, sweet potato, soybean and sugarcane. Narrow corridors near urban markets, such as along riverbanks, are also intensively cropped with vegetables, sesame, beans and fruits. Among the principal fruit crops, there are bananas, mangoes, papayas, breadfruits and oranges.

In the lowland areas, almost half of the crops are grown using irrigation water, and the proportion increases for Mekong Delta region where Kandal province reaches 80%. Water use in agriculture is not measured or recorded, except perhaps by the farmers. Due to this lack of information, water use is estimated as the water volume required for agricultural activities. From these estimations, it was found that agricultural water use accounted for around 95% of total national use (Agricultural Census, 2013). Furthermore, the expansion of crop areas and livestock number is likely to result in increased water demands. Rehabilitation plans for irrigation infrastructures are conducted, but in many cases irrigation schemes are designed to provide supplementary irrigation water for wet season rice farming. In addition, the rainfall pattern has become increasingly irregular and climate change may have serious consequences on irrigated agriculture in Cambodia (Thomas, Timothy et al. 2013). Future water supply must also take into account impacts of large scale hydropower development upstream on the Mekong.

2. Prek history and functioning

Also called « clogging canals », preks are old infrastructures built by the French administration during colonial time. They are located in the Cambodian Mekong Delta, a wide lowland between Phnom Penh and the Vietnamese border where the Bassac and Mekong rivers flow (figure 1). Here, in the Kandal province, preks have been dug perpendicularly to both sides of rivers beds. The original purpose was to convey water and sediments to lowlands (boeungs) during flooding time. Over the years, sediment deposition has shaped raised lands along prek banks so called « chamcars » (Pratx, 2017).

Today, preks are mainly used as water reservoirs for irrigation. They can be seen as irrigation scheme units, in which boeungs are flooded during wet season, allowing rice cropping, while chamcars, never flooded, are suitable for agricultural diversification and perennial crops. Water availability varies according to the rivers' hydrological regimes and climate conditions, and is therefore widely dependant on the monsoon system.

In the framework of the government's strategy for agriculture development and with the financial assistance of international donors, several preks rehabilitation programs have been implemented since 1999. The primary objective of these projects is to improve water availability for irrigation and related crop production in the chamcars and boeungs (SOFRECO, 2019).

2. Study Area

1. Study area definition

The PhD thesis « Understanding Delta Hydrology from an Integrated Perspective - Hydrological Modelling of the Mekong Delta, Cambodia » prepared by Christina Orieschnig focuses on a study area including ten preks on the right bank of the Bassac river, 60km South of Phnom Penh in the Kandal province, Kaoh Thum district (figure 1). Considering the limited internship duration, study area for this project has been reduced to two preks in the southern part of the original study area : prek Chann and prek Touch. These two canals show the advantage of being located next to each other and thus share the same soil and environmental properties, with the difference that prek Chann has been rehabilitated in 2017 while prek Touch has not.

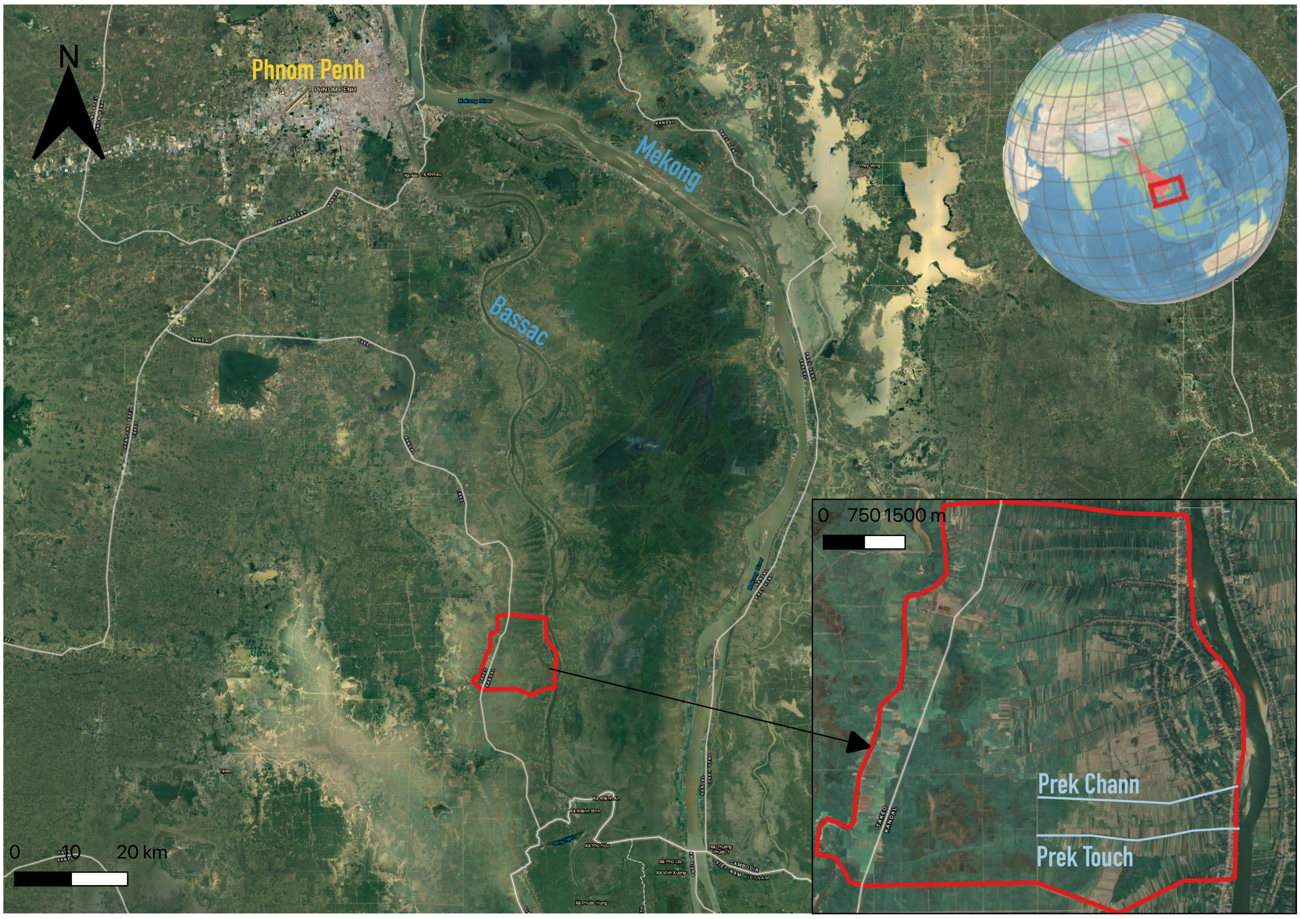


Figure 1. Study area location.

2. Study area description

Prek Chann is located 5.7 km downstream of the Kho Thom bridge on the road 21. The canal has been rehabilitated by Sofreco two years ago. The rehabilitation included the installation of an intake gate (flow control at the connection between the prek and the Bassac) and deep calibration of the prek (deepening of the canal bed down to the lowest Bassac water level in dry season, so that the prek becomes a year-round river water reservoir by gravity).

Prek Touch is the next prek around 500m southward. The canal is not rehabilitated. The main prek properties are described table 1.

	Rehabilitated	Lenght [m]	Command area [ha]	Prek users	Main crops
Prek Chann	Yes	3760	396	135	rice, maize, vegetables (long bean, cucumber, aromatics) and mango.
Prek Touch	No	3730	257	?	rice, mango, soybean and cucumber

Table 1. Preks Chann and Touch characteristics.

Irrigation practices strongly vary between both preks. Indeed, prek Touch is dry from November to July (still dry in mid-August this year, figure 3), while prek Chann appears to be filled the whole year since the rehabilitation (figure 2). Hence, prek Touch farmers reported mainly the boeung and the Bassac river as irrigation source. A farmer at the head of the prek provides pumping services allowing for irrigation on the chamkar with Bassac river water. On the other hand, prek Chann farmers make extensive use of the water from the prek by means of pumping stations along the canal. However, pumping costs may be high for farmers. In case of drought or flooding delay like this year, plots are sometimes abandoned.

Figure 2. Prek Chann tail end, drone view 13/08/19.

Figure 3 Prek Touch tail end, drone view 14/08/19.

3. Methodology

The work period was divided into three distinct phases. The first task consisted of a land use analysis using a GIS classification method. The second mission was a field study combining surveys and observations in situ. These first two achievements provided results used for the last phase of crop water requirements modelling.

1. Spatio-temporal mapping of cropping systems: a supervised classification method using Sentinel-2 images

1. Context

Despite the data from farmer interviews and field campaigns obtained by several development projects in the study area, some important information remains unknown. Indeed, precise crop distribution mapping is needed in order to assess crop water requirements at prek scale. The main objectives are to identify crop type diversity and their distribution in time and space along the preks. For this purpose, a remote sensing analysis is carried out using the GIS software QGIS 3.4 and the semi-automatic classification plugin 6.3. The method employed is a supervised classification (guided by the user to specify the land cover classes of interest) on Sentinel-2 images.

2. Workflow for land cover mapping

Land cover mapping is based on the analysis of four S2 images acquired for the year 2018 with a three months step (when possible). Images were chosen depending on a typical crop calendar but also on the basis of sufficiently low cloud cover, hence the lack of correct data for the month of July (figure 4).

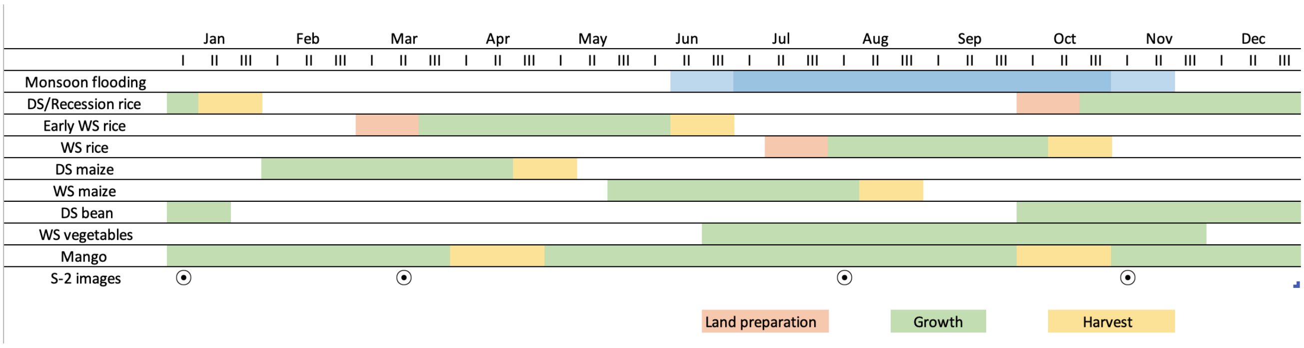


Figure 4. Typical crop calendar in the study area and S-2 images shooting dates.

The general workflow is divided into four main steps, as displayed in figure 3 :

1. Semi-Automatic Classification plugin installation and image download.
2. Pre-processing (radiometric correction, creation of spectral indices, clipping of the study area).
3. Supervised classification (creation of training sites, assessment of spectral signatures and classification).
4. Assessment of the classification accuracy and post-processing.

3. Introduction to SCP and S2 images

i. Semi-Automatic Classification plugin

SCP is a free open-source plugin developed by Luca Congedo, allowing for the implementation of a supervised classification on a variety of satellite images such as MODIS, Landsat or Sentinel 1-2-3. In addition to the classification module, the plugin also provides many tools for images preprocessing (download, surface reflectance conversion, clipping, indices computation etc.) and post processing (accuracy assessment, reclassification, sieve classification etc.). The plugin is available through the plugin download function in QGIS and requires the default installation of GDAL, OGR, Numpy, SciPy and Matplotlib.

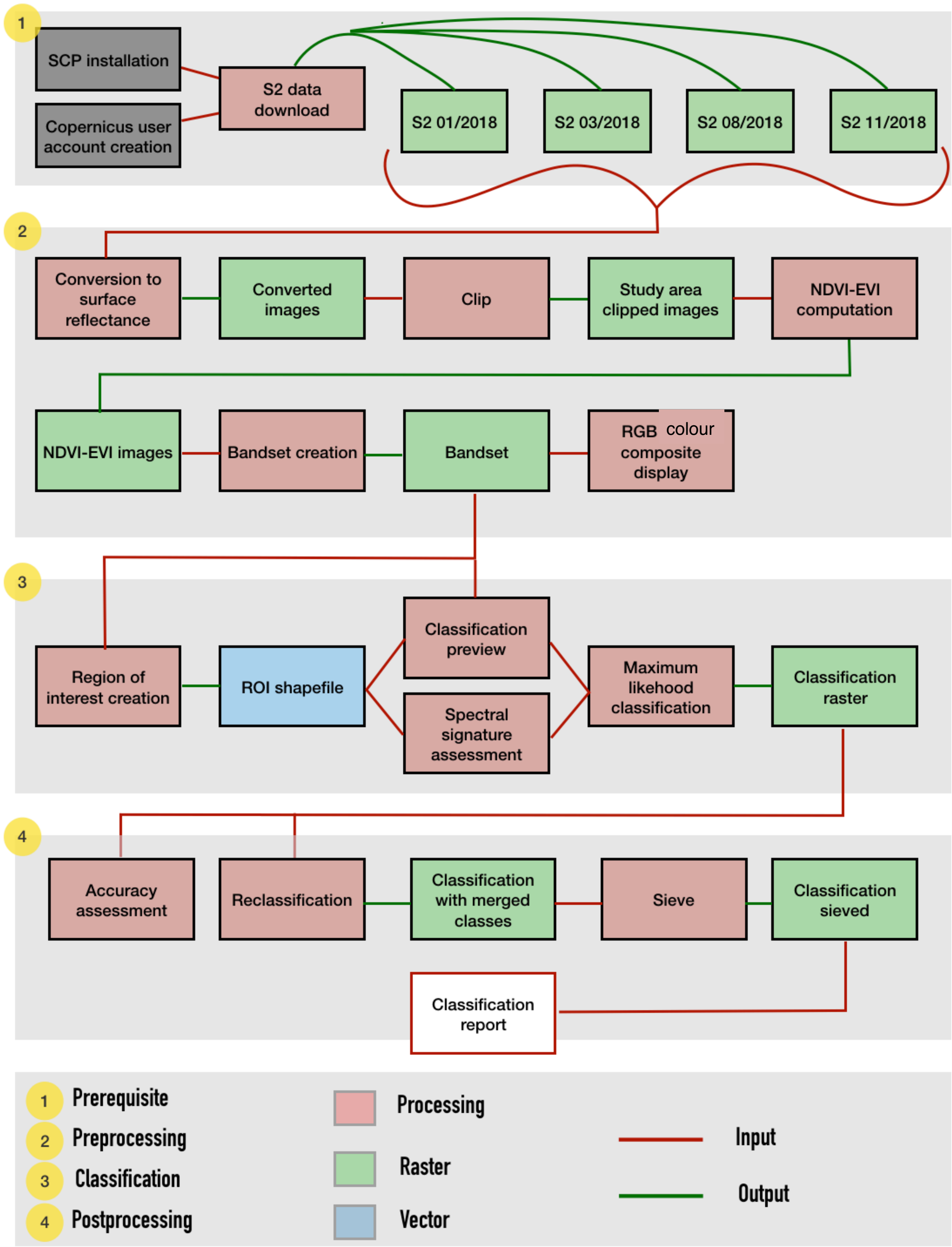


Figure 5. Workflow for land cover mapping using SCP for QGIS.

ii. Sentinel 2 images

The Sentinel 2 mission is based on a constellation of two satellites (S2A and S2B) with high spatial resolution and high revisit times (5-day). It was developed by the ESA as part of the Copernicus earth observation program funded by the European Union. S2 acquires images in 13 spectral bands with spatial resolutions ranging from 10 to 60 m (depending on the spectral band considered), thus allowing a wide variety of applications for the monitoring of continental surfaces (in particular the characterization of vegetated surfaces) (ESA, 2015).

4. Preprocessing phase

Pre-processing is a list of operations aiming to prepare images for the classification. As displayed in the workflow figure, S2 images are converted to surface reflectance before clipping (conversion works better on the whole image). For each date, two clips are created : one for the prek Chann area and the other for prek Touch. Spectral indices are then computed and a bandset is created for the classification.

i. Conversion to surface reflectance

In order to correctly classify the land use, images have to be corrected for the effects of solar irradiance in apparent reflectance (Top of Atmosphere (TOA)) and for effects of the atmosphere in surface reflectance (Top of Canopy (TOC)). As Sentinel 2 data are already provided in TOA, only the conversion in TOC is needed. SCP plugin is then used to implement a DSO1 (Dark Object Substraction) correction that leads to images converted to reflectance. This information is present in the metadata file associated with the downloaded images. Although the accuracy of this method is generally lower than that of physical process-based methods, it has the advantage of not requiring measurements of atmospheric conditions (Congedo, 2019).

ii. Clipping to the study area

Sentinel 2 downloads cover a square area of 110 km2 (representing around 3GB) and the classification process could consequently be extremely time-consuming. Moreover, additional information is added by converting and computing spectral indices. It is therefore necessary to reduce pictures to the study area and this is what clipping does. As the aim is to classify land use patterns at prek scale, two clips are implemented for each sentinel picture : one for prek Chann and the other for prek Touch.

iii. Spectral indices

In order to highlight certain surface properties that are not visible on the original channels, new channels are created from the linear combination of reflectances in different wavelengths. Two indices are chosen in this case : the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). They are computed thought the band calculation function of the SCP plugin.

The well-known and widely used index is NDVI, based on the reflectance in the red and the near-infrared spectral areas whose difference increases with the density of green leaves and therefore with the chlorophyll concentration of the canopy (Sentinel 2EO Products). It is therefore a good indicator of the amount of green vegetation:

$$NDVI = \frac{\rho NIR - \rho R}{\rho NIR + \rho R}$$

where ρNIR is the reflectance in the near-infrared and ρR the reflectance in the red. The NDVI is a normalized index with values ranging from –1 to 1. For bare soils, NDVI values are close to 0 (due to small differences between the red and the infrared); for vegetated areas, NDVI values can vary from 0.1 to 0.8–0.9 (very dense and green canopy). However, NDVI is sensitive to the type of soil (for sparse vegetation cover), to atmospheric effects and viewing conditions and tends to saturate for dense vegetation (Mulla, 2013).

To improve NDVI values, EVI is then computed :

$$EVI = 2.5\frac{\rho NIR - \rho red}{\rho NIR + 6\rho red - 7.5\rho blue + 1}$$

where ρNIR and ρred are still reflectance in the near-infrared and red, and ρblue the reflectance in the blue. Information provided by the blue band allows the improvement of precision where the Leaf Area Index (LAI) is high. NDVI and EVI results are compared bellow for prek Chann the 12th of March 2018 (figure 6).

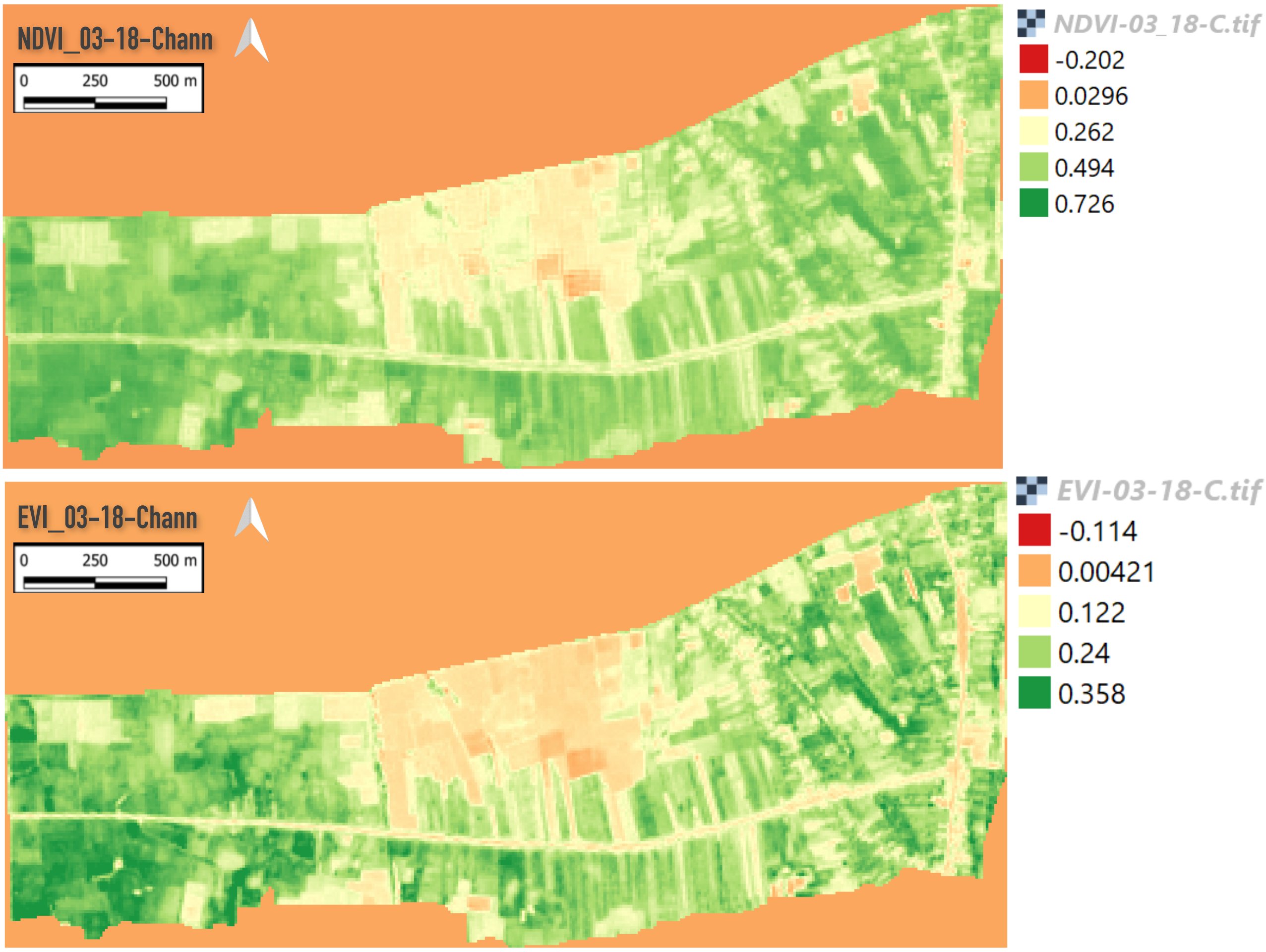


Figure 6. Spectral indices comparison, prek Chann 12/03/2018.

iv. Creation of the bandset

Once the spectral bands are converted and clipped, and the new spectral indices are created, the last pre-processing step consists of creating a group of layers containing all the bands necessary for the classification process, also called a "band set". It is therefore necessary to create a single dataset from the set of initial bands and spectral indices. This step also makes it possible to display combinations of bands (or color composite images) to facilitate visual discrimination of the different elements in the image (Figure 7).

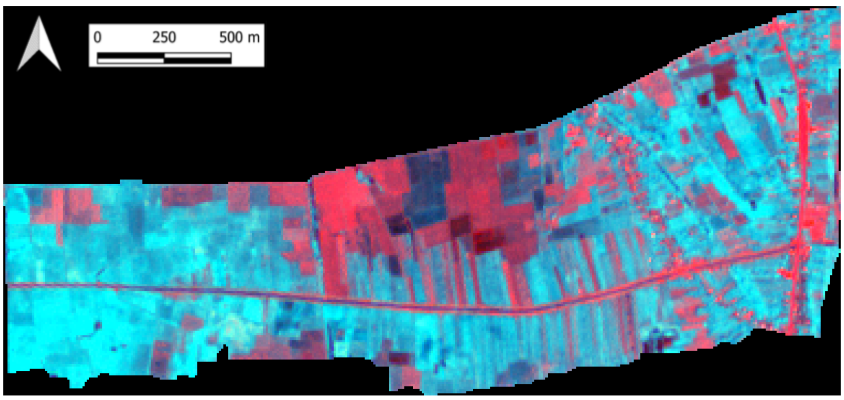


Figure 7. Example of a color composite (NIR,R,B) image, prek Chann 12/03/2018.

5. Land cover classification

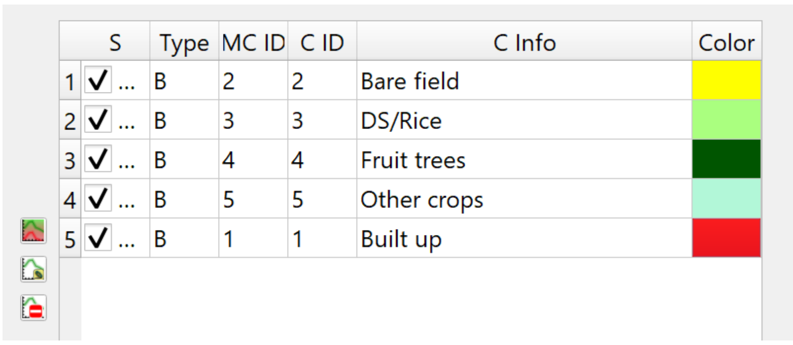
The classification of a satellite image consists of gathering pixels with common spectral characteristics into homogeneous groups (classes). There are two main types of classification : the unsupervised classification where pixels are gathered automatically according to their own structure, and the supervised classification where the user defines reference objects for selected classes before the classification algorithm finally group pixels according to these training sites. The supervised method for land cover classification is thus divided into four steps as follows : creation of training sites, definition and analysis of their spectral signatures, classification and accuracy assessment of the classification.

i. Creation of ROIs

The creation of training sites (ROI-Region Of Interest) is performed by the user, and aims to provide spectral information to each land cover class. The delineation is done by drawing polygons on representative objects on the image, between macro classes and within classes (intra-class variability). For example, a macro class will be called « cropped area » within several classes such as rice, fruit trees, vegetables; another macro class will gather built up objects etc (figure 8). The main challenge lies in making intra class separability, indeed crops spectral signatures might be really close. To improve the classification quality, the training database has to be expanded as much as possible, following the guidelines below :

- training sites areas have to be sufficiently wide to consider class specific properties;
- each class has to be represented by several training sites distributed evenly over the image;
- each training site must be as homogeneous as possible;
- photo interpretation, indices and several color composite are useful to best identify classes.

However, it is important to notice that the ROI creation through photo interpretation is subjective and will depend on user choices. This is why it is better to have a training site database obtained from a field campaign.



	S	Type	MC ID	C ID	C Info	Color
1	✓ ...	B	2	2	Bare field	
2	✓ ...	B	3	3	DS/Rice	
3	✓ ...	B	4	4	Fruit trees	
4	✓ ...	B	5	5	Other crops	
5	✓ ...	B	1	1	Built up	

Figure 8. Example of classes during ROI creation.

ii. Classification preview and spectral signature analysis

Classification preview is a tool allowing to display a temporary raster with classes according to drawn training sites. Carried out on a portion of the image, it is a quick way to make a qualitative assessment of the training database. In addition, the quality of the ROI creation is assessed by analysing the spectral distance between the different classes. If classes are weakly separable, the risk of confusion between these classes in the final classification is high. The objective of this phase is to check that classes are homogeneous and if there are separable.

There are different measures of spectral distances that are chosen according to the specific classification algorithm (Congedo, 2019) :

- the Jeffries–Matusita distance, usually used for a Maximum Likelihood classification;
- the Spectral Angle, for a Spectral Angle Mapper (SAM) classification;
- the Euclidean distance, adapted for Minimal Distance classification;
- the Bray–Curtis similarity, which allows analyzing the similarity between two given samples.

In pratical terms, spectral signatures are plotted to estimate which signatures are too close. In the displayed example (figure 9), the cropped land macro class seems homogeneous gathering three classes (green colours). Distance still have to be checked between bare soil and built up macro classes, as spectral signatures look very close. The distance table is then computed (Table 2) : spectral signatures are effectively close, too much for discrimination with SAM or minimal distance algorithms, but far enough for Maximum Likelihood classification (Jeffries–Matusita distance value near 2.0).

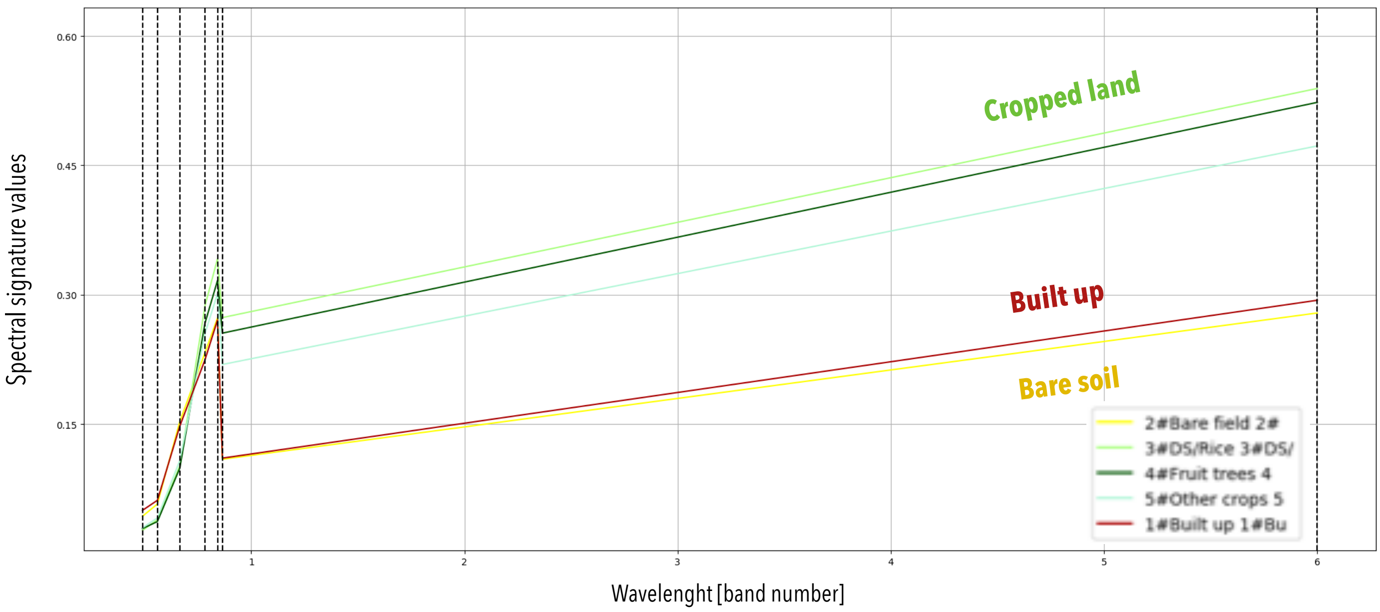


Figure 9. Spectral signature plot with SCP plugin.

As long as spectral signature distances do not allow accurate discrimination between classes, new training sites have to be drawn, signature values have to be modified, thresholds might be applied. This iterative process is the longest and most tedious step in the classification process. Moreover, some of the crop spectral signatures appear definitely too close to pertain to a specific classification, especially for perennial crops where time-serie comparison does not help for crop identification. Therefore, some species will be gathered under one generic designation such as « fruit trees » (mainly mango and papaya trees). This simplification will not meaningfully impact the modelling results in terms of crop water requirements as species gathered seem to show similar crop coefficients (Allen et al., 1998).

	MC_ID = 2 MC_info = Bare field C_ID = 2 C_info = Bare field
	MC_ID = 1 MC_info = Built up C_ID = 1 C_info = Built up
Jeffries-Matusita distance	1.7093710304517218
Spectral angle	2.232909190839229
Euclidean distance	0.01968084819811234
Bray-Curtis similarity [%]	98.12356489007469

Table 2. Spectral signature distances between macro classes.

iii. Classification

The classification step concerns the extrapolation of the entire image of the previously identified training sites, and for which a thematic land cover class could be attributed via a classification algorithm. The algorithm classifies each object (or pixels) present in the image by comparing its spectral characteristics with those of the reference objects in the training database. The algorithm chosen for this classification is Maximum Likelihood, which assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class (Congedo, 2019). In fact, in the absence of field observations and a land use database, different algorithms have been tried and the most likely result according to photo interpretation and area knowledge has been selected.

6. Classification accuracy assessment and post-processing

i. Classification accuracy

Assessment of the classification accuracy is a fundamental step of the process which allows to determine if the mapping is suitable or not. According to this result, classification data and method may be used or sidelined. To do this, the classification results are compared with reference data (independent of those used to perform the classification) by means of a confusion matrix (Ghazaryan et al., 2018). Ideally, the testing dataset should come from field observations or alternatively from photo-interpretation of a satellite image.

ii. Post-processing

- Merging classes : analysing the confusion matrix can identify classes with strong spectral similarities (close spectral signatures) and for which discrimination is not necessary or possible. In this case, the merging post processing tool allows to merge those classes.

- Sieve tool : even with a suitable classification performance, some isolated pixels may be observed within large areas of other classes. This post-processing tool allows to harmonise the map, substituting isolated pixels with the majority class in the pixels surrounding (figure 10).

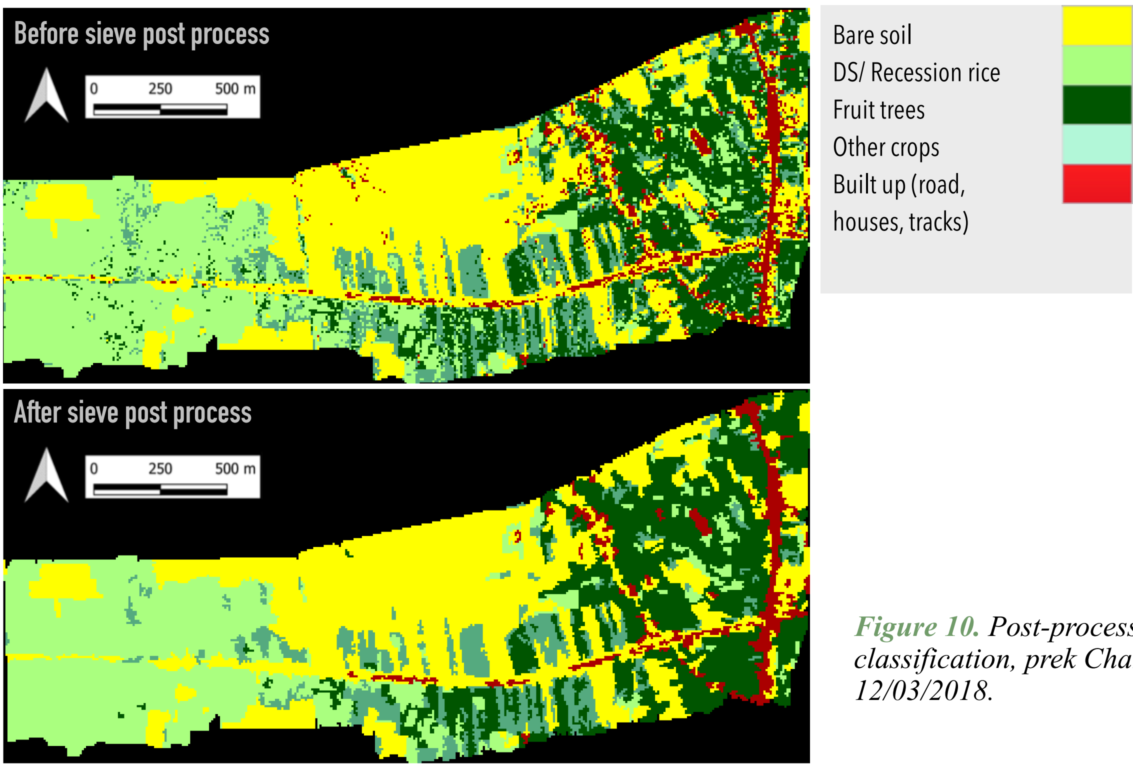


Figure 10. Post-processing on classification, prek Chann 12/03/2018.

2. Field survey

The field trip took place between the 13th and the 15th of August 2019 and focused on preks Chann and Touch, Koh Thom district, Kandal province. In order to assess crop water requirements, data about cropping patterns (crop types, calendars and areas) were collected by means of farmers interviews. In addition, information about actual irrigation practices (irrigation interval, pumping times and characteristics, irrigation source) were also collected for each crop. Some questions about yields, crop losses and market distribution were added for further study (yield response to irrigation, links between hydrological regime variations and production, risk concept etc.). Interviews were carried out through a survey grid and participatory maps (Annexes 1, 2). The questionnaire consisted mainly of closed questions providing both quantitative and qualitative data, although discussion time was reserved at the end of the interview. The help provided by Mrs. Thary Vorn of the Royal University of Agriculture was extremely valuable and allowed positive exchanges with the locals. In total, four farmers were interviewed on each prek.

In addition to these surveys, the field phase provided an opportunity for general observations (topography, flood level, GPS points, hydraulic infrastructures, pumping methods, drone shots, etc.).

3. Crop water requirements modelling

Crop water requirements (CWR) assessment is performed by means of the FAO software CROPWAT 8.0. The objective is to compute the main crops' potential evapotranspiration (ETc) throughout the year according to environmental conditions (climate, soil) and agricultural practices (land use, crop calendar).

1. Calculation of reference evapotranspiration

The reference evapotranspiration (ETo) represents the potential evapotranspiration of a well-watered grass crop, and other crops 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 :

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

where

ETo - reference evapotranspiration [mm day-1],
Rn - 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],
es - saturation vapour pressure [kPa],
ea - actual vapour pressure [kPa],
es - ea - 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 3).

2. Processing of rainfall data

Rainfall is a variable factor from year to year and according to the seasons. In Cambodia, the rainy season (May-November) is marked by rainfall between 100 and 300 mm/month. During the dry season (December-April), rainfall varies from 0 to 50 mm/month. This seasonal variation leads to different levels of CWR satisfaction depending on the month of the year. Average monthly rainfall data at the Phnom Penh meteorological station are provided by the CLIMWAT database.

In addition to the variability of rainfall from year to year, 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) :

$$Pe=0.8 \times P-25 \text{ if } P>75 \text{mm/month}$$
$$Pe=0.6 \times P-10 \text{ if } P<75 \text{ mm/month}$$

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. Monthly rainfall and effective rainfall are displayed figure 11.

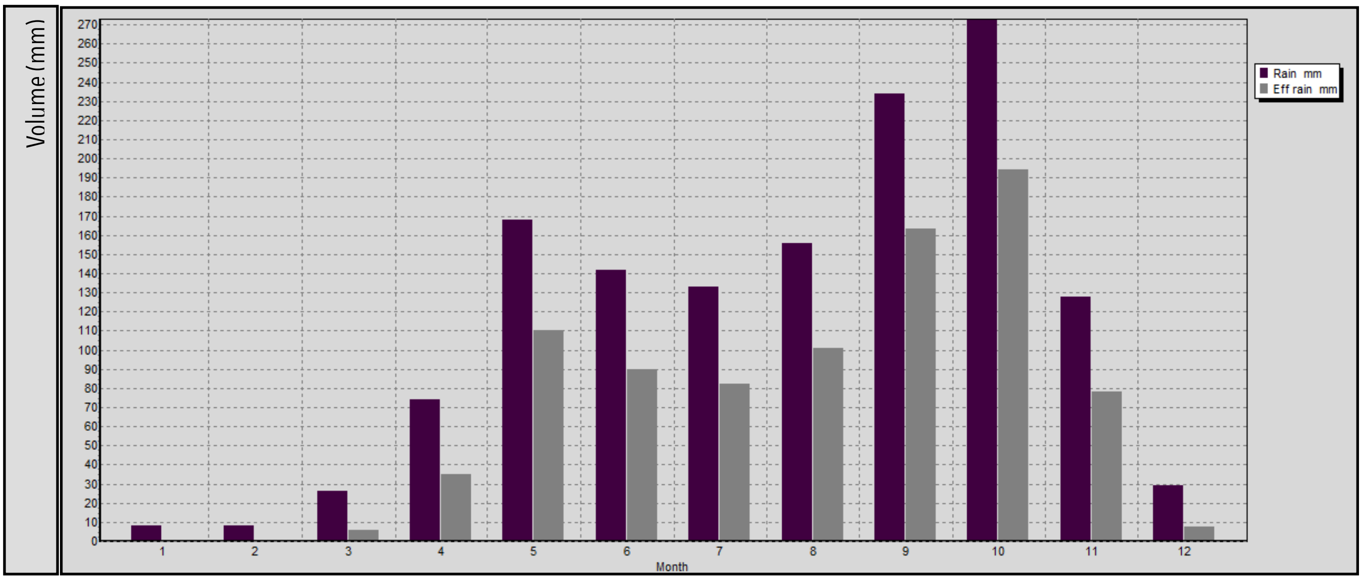


Figure 11. Rainfall (Phnom Penh station) and effective rainfall (dependable rain).

3. Soil data collection

Soil characteristics do not differ between both preks but change along the preks. Indeed, a distinction has to be made between chamkar (upland) and boeung (lowland) soils :

- On the chamkar, the top soil has a very little coherence and varies from red to light brown.
- On 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.

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 and red sandy loam for the chamkar (annex 4).

4. Crop and cropping pattern information

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. Figure 12 displays an example of necessary crop data for a paddy rice water requirements calculation. In order to extend the model to irrigation scheme scale, a cropping pattern is defined for each prek, including crop distribution information from the GIS analysis (annex 5).

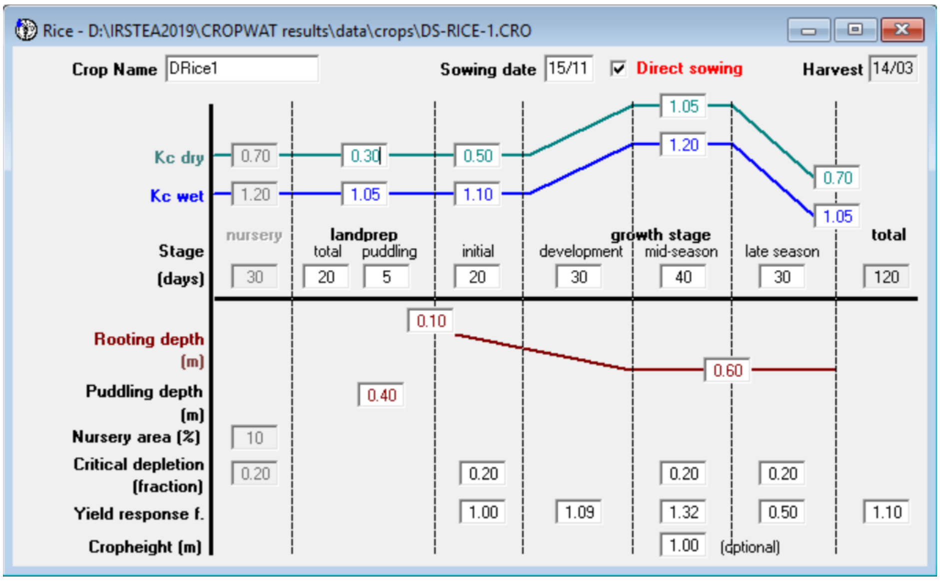


Figure 12. Crop data input on CROPWAT 8.0.

5. Crop 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 the crop characteristics such as :

$$ET_c = K_c\ ET_o$$

where

ET_c *crop evapotranspiration* $[mm.d^{-1}]$,
K_c *crop coefficient* $[dimensionless]$,
ET_o *reference crop evapotranspiration* $[mm.d^{-1}]$

Reference evapotranspiration is computed as explained above, while the crop coefficient (Kc) is provided by FAO Irrigation and Drainage Paper No. 56.

4. Results and discussion

1. Cropping systems

On average, farmers own 2 or 3 plots. Sometimes plots are divided into cropping units - for example 0.6 ha on the chamkar are divided into 0.2 ha of aromatics, 0.2 ha of long beans and 0.2 ha of cucumbers. Along prek Chann, main crops are rice, maize, vegetables (long beans, cucumbers, aromatics) and mango trees. Along prek Touch, the main crops are rice, mangos, soybeans and cucumbers. Over the last years, maize cropping areas decreased because of water scarcity. Instead, fruit trees which are less affected by water shortage have been planted. Farmers have provided very precise information about land use and cropping calendars. The results of the survey are displayed below, with the dates of Sentinel2 images used for the land use classification.

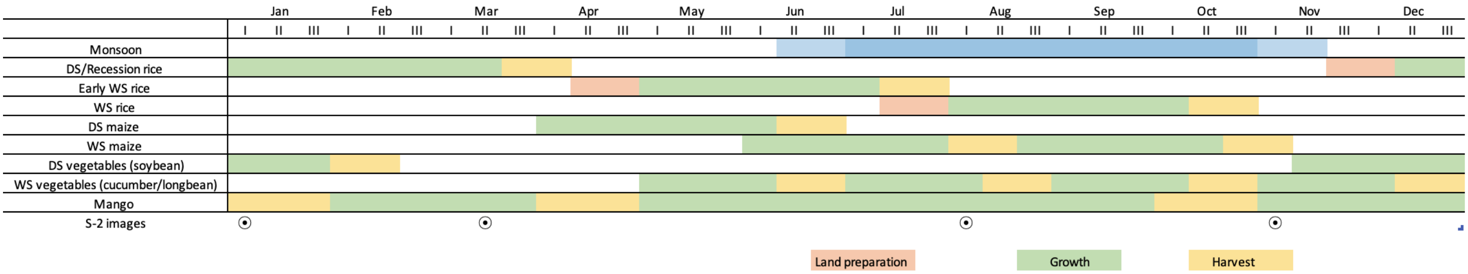


Figure 13. Cropping calendar in the study area, survey results.

Land preparation takes two weeks on average. Rice is sown through the broadcasting method. The monsoon flooding period represented above is the typical one, but does not take into account exceptional years (eg. flooding delay this year) - which are likely to become the norm due to climate change and hydropower-induced flow alteration (Hecht, 2019). On the chamkar of prek Chann, four vegetable harvests are possible during the wet season. This is not the case at prek Touch where the lack of rain and the dryness of the prek make access to water expensive. On mature mango trees (more than 5 years old), three harvests per year were reported. Mango trees are the most widely cultivated fruit trees, but banana and papaya trees have also been observed in association (alternating rows).

2. Land use change

The analysis of the reports from the classifications of satellite images allowed to establish land use proportions (crop types, bare soil, flooded areas) depending on the image dates. Figure 14 displays results for crop area percentages along the year on preks Chann and Touch. Crop type proportions are relatively close between both preks. The proportion of land flooded during the wet season is higher for prek Chann (around 42% in August). At the same time, the proportion of land allocated to wet-season rice cultivation is higher for prek Touch. Differences in the cropping calendar (often due to differences in water availability) are observed in the land use results. In November for example, no rice cultivation was observed in the prek Chann area, while 10% of the prek Touch land is reserved for wet season rice. This can be explained by earlier sowing of rice (early August) at the prek Chann level, due to better water availability. As a result, rice is harvested in late October along prek Chann and during November in prek Touch area. The chosen dates for satellite images are retrospectively questionable, as the months of January and November appear to be transition months between harvest and planting. Hence it would be wise to plan a field trip (or consult the crop calendar produced) before the GIS classification next time, in order to properly choose the satellite images dates.

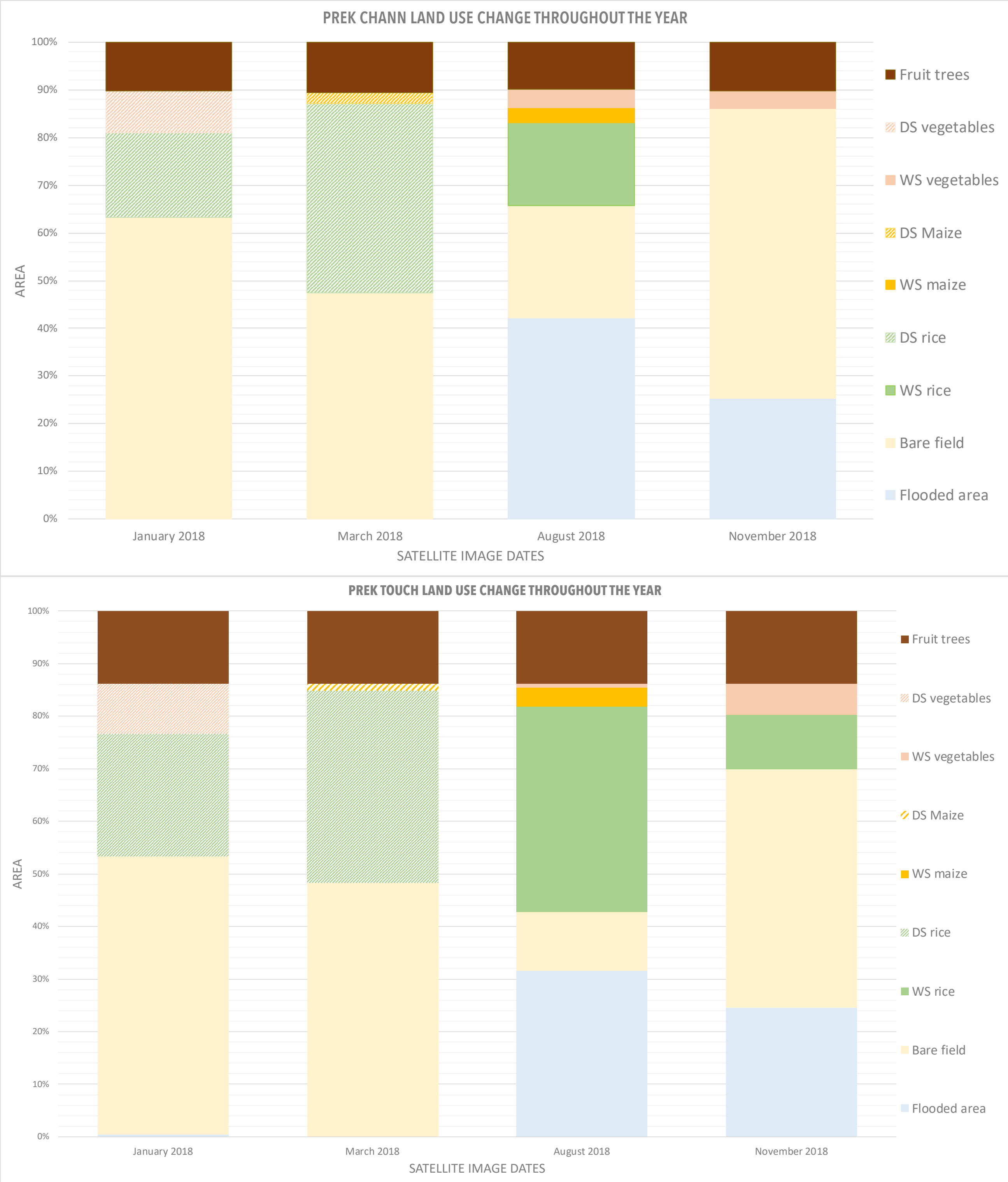


Figure 14. Land use change on preks Chann and Touch areas, 2018.

The classification allowed also to spatially identify the land cover change, for a better understanding of the flood phenomenon and its consequences for agricultural land use. On the prek Chann map below (figure 15), flooding is near its maximum at the beginning of August 2018 and around 40% of the area is submerged. Distinctions between lowlands and uplands is easily identifiable.

Figure 15. *Prek Chann map after classification, 08/08/18.*

3. Crop water requirements

Crop water requirements (CWR) are computed for each main crop on both preks (figures 16-17). Climatic data being the same and assuming that crop varieties do not differ between the schemes, the only difference in the results lies in the cropping calendars variations. Indeed, the survey showed some differences for sowing dates mainly linked to water availability. Moreover, water availability in prek Chann also allowed for two maize and two vegetables crops consecutively during the wet season, which is not possible along prek Touch.

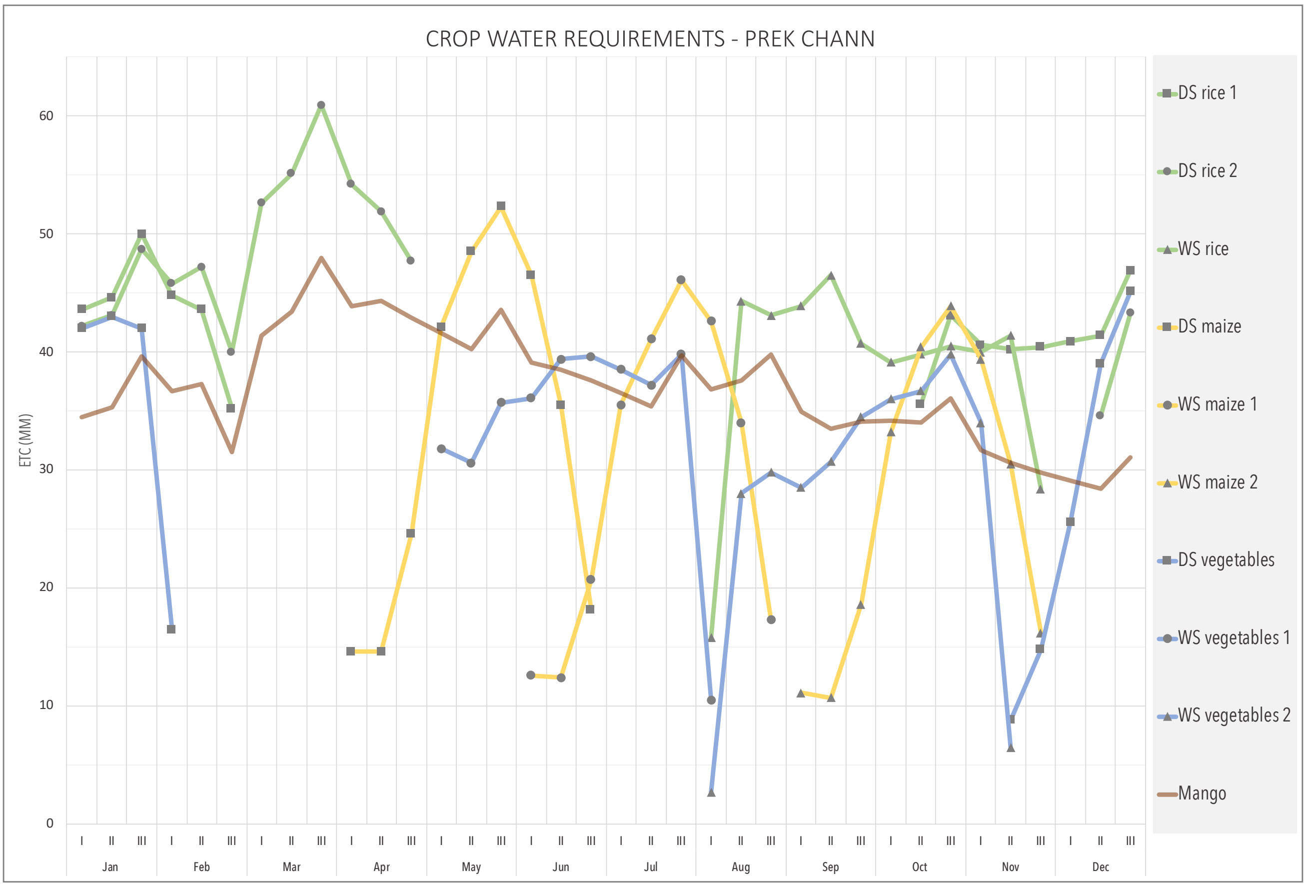


Figure 16. *10-days step CWR on prek Chann.*

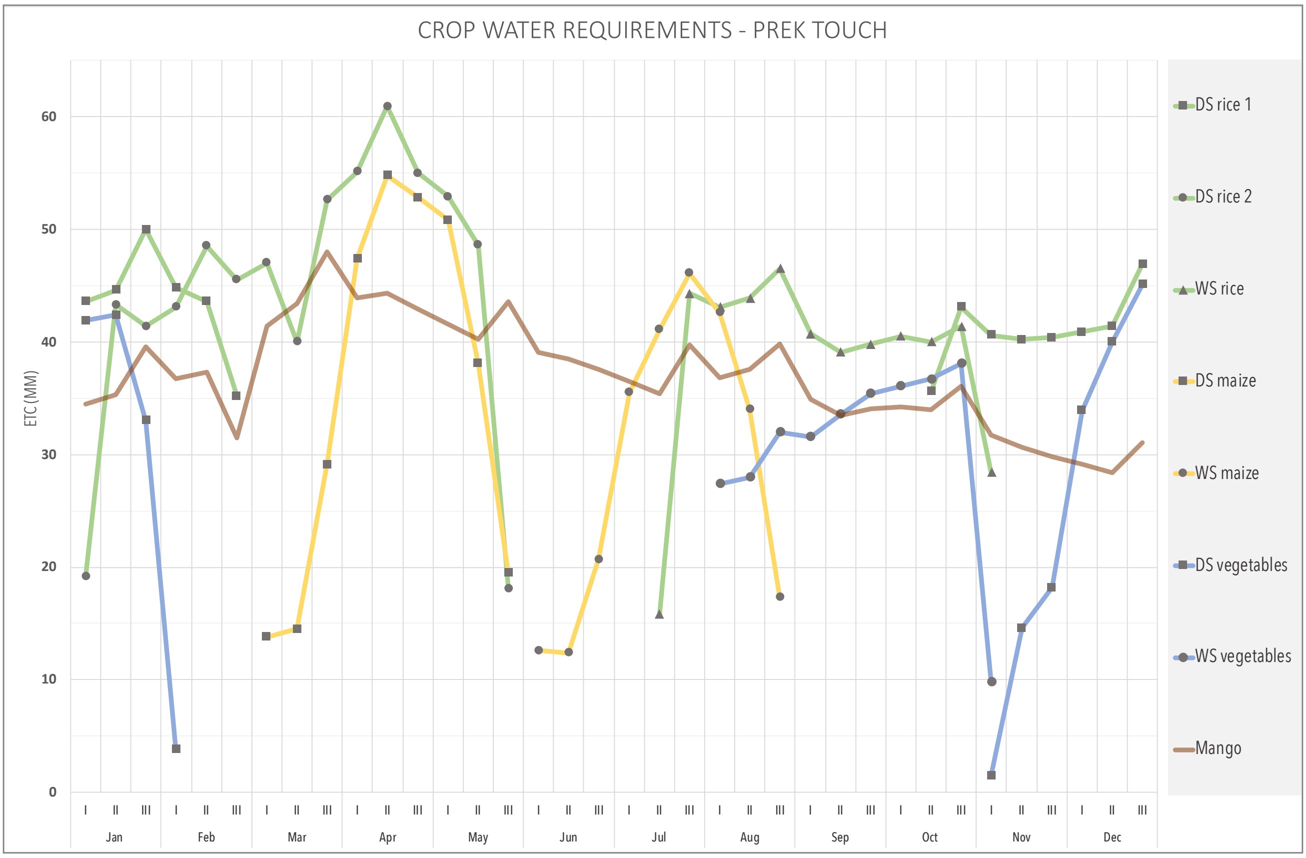


Figure 17. 10-days step CWR on prek Touch.

4. Net irrigation required at crop scale

Crop irrigation requirements along the year are computed by subtracting monthly effective rainfall to CWR. Net irrigation required is calculated for each crop, and in other words provides the rainfall deficit. Figure 18 displays an example for a recession-dry season rice sown the first decade of November on prek Chann. The two decades of October show a high amount of required irrigation, due to the high demand of the land preparation. Then, irrigation volumes needed to meet the CWR increase as the wet season turns into the dry season. From mid December to the rice maturity and harvest in February, effective rainfall is near zero and CWR need to be fully supplied by irrigation water.

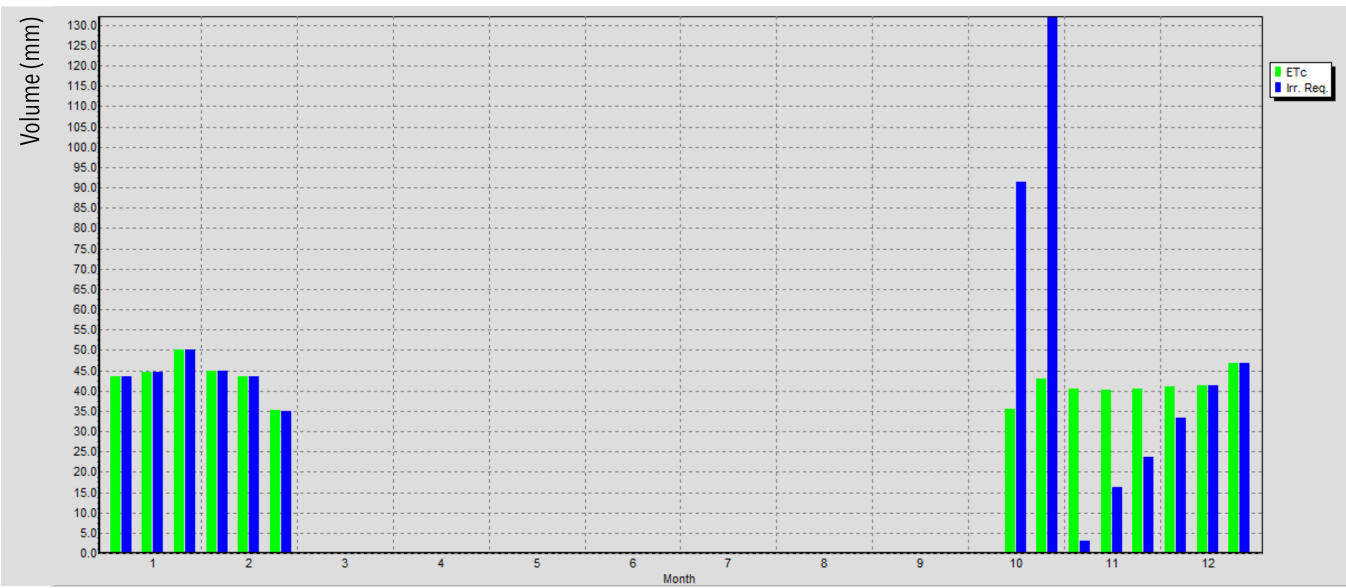


Figure 18. ETc and irrigation requirement for a recession DS rice, sowing date November 1st, prek Chann.

5. Net irrigation required at prek scale

By connecting land use results with crop irrigation requirements, net irrigation required at prek scale is computed according to the month of the year. Volumes required are compared between both preks (figure 19). The area of prek Chann is approximatively 150 ha larger than the area of prek Touch, crop types are the same but crop calendars are different. Irrigation volumes required are lower during the wet season and reach their highest levels in December when effective rainfall is low and dry season rice areas are at their peak. In July, required irrigation volumes appear larger on prek Touch, due to earlier sowing for wet season rice and larger maize areas.

The irrigation scheme scale modelling is useful for comparisons of water availability in the canal along the year. It allows to plan the design according to potential crop water requirements. For example, the prek Chann canal should be able to supply at least 500.000 m3 in December in order to ensure crop water needs. Nevertheless, the modelling appreciates net irrigation volumes, and does not take into account application and conveyance efficiences. In fact, conveyance and application conditions vary from one cropping system to another, and especially between the boeung and the chamkar areas. Therefore, a focus study about irrigation efficiency should be carried out in order to estimate gross volumes applied and pumped volumes required in the preks.

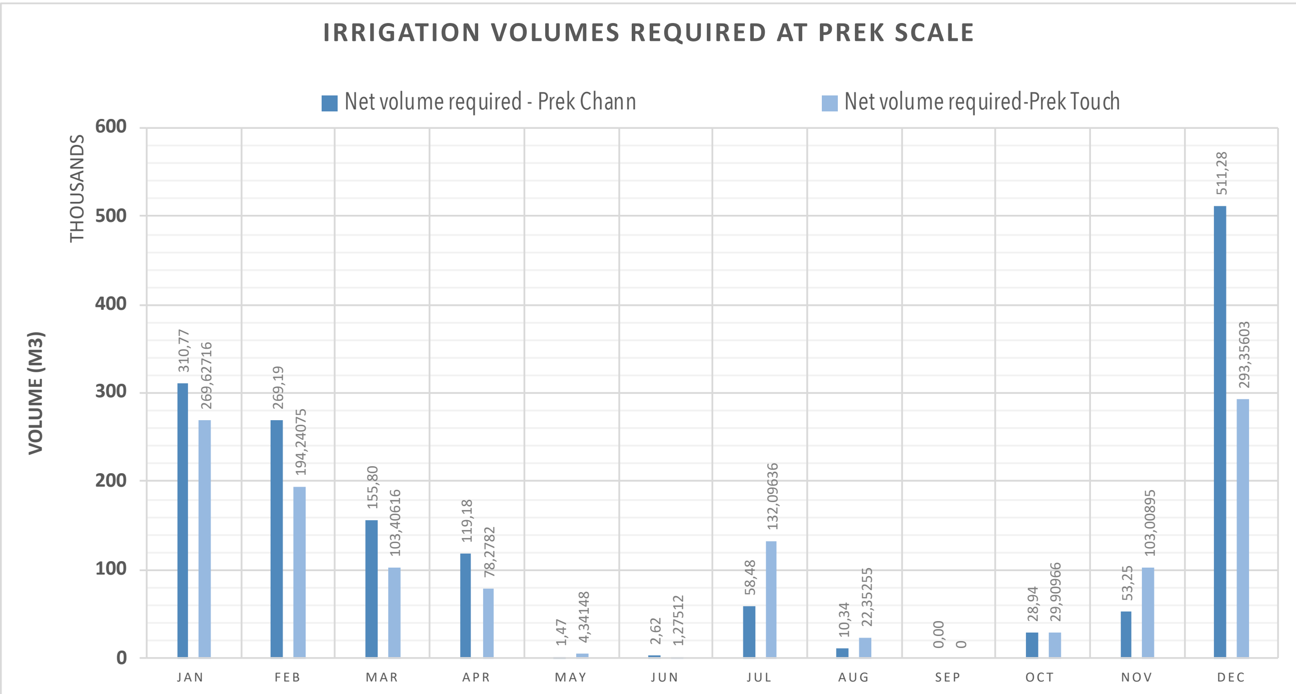


Figure 19. Net irrigation volumes required at irrigation scheme scale.

6. Agricultural production and yield response to water availability

Regarding the question of crop production, different kinds of answer are obtained from the farmers. Sometimes they know precisely how many kilograms are harvested on a plot. In that case, yield is then computed according to production (kg) and area (ha) information. In other cases, some farmers only know about the revenue they get from a plot. In that case, yield is deduced using the market price (riel/kg). In so doing, an average yield is calculated for each crop and compared when possible between the preks (figure 20). Information collected about mango trees on prek Touch do not allow yield estimation yet as trees were too young for production (less than 5 years old). Moreover, production information is sometimes not known in the case of family consumption or excessive losses.

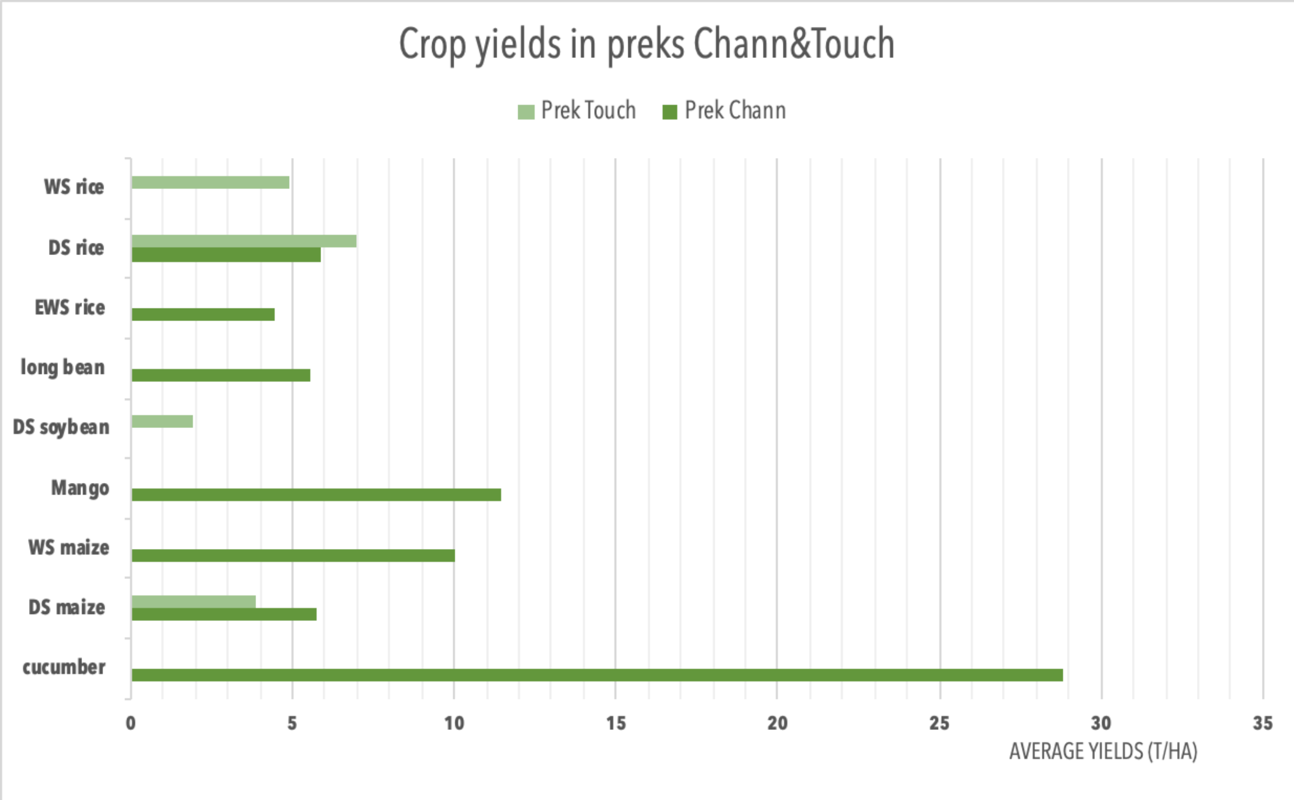


Figure 20. Average crop yields in preks Chann and Touch, survey 08/19.

These results provide an idea of actual yields in the area and farmer's knowledge about production rates. Further studies would be necessary in order to precisely compare crop productions between both preks. Without a larger sample and a statistical study, it is impossible to draw conclusions about the significance of the results here. Nevertheless, it may be interesting to associate differences in yield rates with differences in water availability. Is the difference in dry season maize yields between the two preks an expression of the yield response to water availability ? Yield variations may be caused by several factors. The results of the survey to the question of yield losses are displayed figure 21.

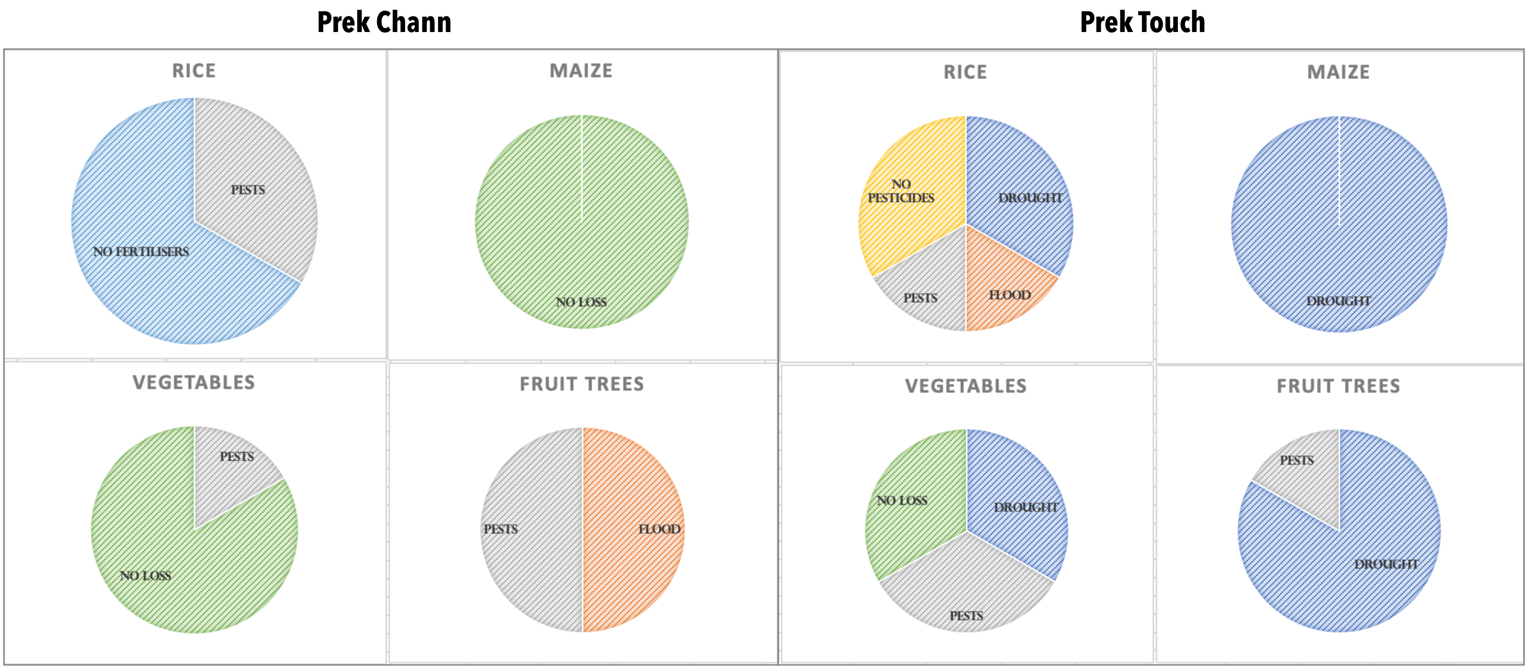


Figure 21. Causes of yield losses, as a percentage of responses, survey 08/19.

Once again, the sample size does not allow statistical conclusions. Nevertheless, a first impression of the situation is provided. Yield loss reasons are economic (fertilisers/pesticides/pumping too expensive), biological (crop diseases/pests) or hydrological (flood/drought). More yield losses have been mentioned on prek Touch, especially because of drought. Also, the drought seems to fully explain yield losses for maize on prek Touch while it is not reported as a problem on prek Chann. This high yield response of maize to water scarcity explains why farmers decided to give up maize in favour of fruit trees. But water availability uncertainty may also causes damage to fruit trees as reported by the farmers : the young plants have suffered from drought and flooding already drowned some mango trees planted too low on the chamkar.

5. Limits and prospects

This study represents a first step toward understanding prek agricultural systems and its relationships with water availability. In view of the stakes and issues raised, many questions remain to be explored. Thus, some points will require a more in-depth study, in particular the question of actual withdrawals from water resources based on survey data. A larger number of interviewees would be necessary in order to propose significant results.

Among the input data for the CWR modelling, weather conditions precision (Phnom Penh airport meteorological station) could be improved by using a local station. Soil data collection would benefit further study (profile, porosity, infiltration capacity) in both low and uplands for a better understanding of water transfers within plots.

The extension of the study should focus on the assessment of performance indicators such as application and conveyance efficiences of irrigation water. In that way, gross volumes required at plot scale and pumped volume needed could be estimated. Then, irrigation volumes required may be compared to :

- actual pumped volumes (some data has been collected during the survey but not enough for a prek scale extrapolation);
- actual or valued water ressource availability during the year (water volumes in preks and pounds, flood levels) ;
- the prediction of possible changes in water ressource availability (impact of dams, climate change, disturbances upstream).

The phenomenon of drought and delayed flooding observed this summer (08/19) seems to indicate problems of variation in water availability with severe consequences on the agricultural sector. Directly related to a study comparing irrigation water requirements with available water resources, research about yield response to water availability and crop water productivity should be carried out in order to assess potential impacts of water scarcity and propose alternatives.

Conclusion

Preks appear as particular irrigation schemes with diversified agricultural production. Within these units, a distinction is made between lowlands (seasonally flooded and suitable for rice cultivation) and highlands (allowing diversified production). The difficulty in understanding the system therefore lies in the spatial and temporal variations of the couple crop water requirements and availability of water resources. The GIS analysis combined with the fieldwork provided some answers to the distribution of crops in time and space. Subsequent modelling of crop water requirements has made it possible to estimate the net irrigation volumes required at the scale of the plot or irrigation scheme. The results can be used as a basis for further study, in particular through work on the efficiencies of irrigation water supply and application. Knowledge of the volumes required allows comparison with actual pumped volumes and available water resource. It also allows the establishment of scenarios based on the forecasts of resource variation, and the possible proposal of alternative solutions.

References

Allen R.G., Pereira L.S., Raes D., Smith M. 1998. « FAO Irrigation and Drainage Paper No 56. »

Congedo L. 2019. Semi-Automatic Classification Plugin Documentation Versión 6.2.0.1 Luca Congedo. https://buildmedia.readthedocs.org/media/pdf/semiautomaticclassificationmanual-es/latest/semiautomaticclassificationmanual-es.pdf.

ESA. 2015. « SENTINEL-2 User Handbook. » In , 1–64. https://sentinel.esa.int/documents/247904/685211/Sentinel-2_User_Handbook.

Ghazaryan G., Dubovyk O., Löw F., Lavreniuk M., Kolotii A., Schellberg J. & Kussul N. 2018. « A rule-based approach for crop identification using multi-temporal and multi-sensor phenological metrics », European Journal of Remote Sensing. 51(1), pp. 511–524.

Mulla, D. J. 2013. « Sensing in Agriculture Review Twenty five years of remote sensing in precision agriculture : Key advances and remaining knowledge gaps 5 », Biosystems Engineering, 114(4), pp. 358–371.

National Institute of Statistics, Ministry of Planning, Ministry of Agriculture, Forestry and Fisheries. 2013. Census of Agriculture of the Kingdom of Cambodia.

Pratx, O. 2017. « Etude Du Fonctionnement Hydro-Agricole de Canaux d'irrigation : Cas Des Preks Sur Les Rives Du Bassac Au Cambodge ». MSc. thesis ENGEES, SupAgro, AgroParisTech, Université de Montpellier.

Laboratory for geographical information systems, Sinergise. « Sentinel 2 EO Products. » https://www.sentinel-hub.com/develop/documentation/eo_products/Sentinel2EOproducts. Accessed July 5, 2019.

SOFRECO. 2019. Water & Agriculture Sector Programme (WASP) – Package 2. « Technical Assistance for the implementation of Preks of Kandal Component (TA-Preks), final report ».

Thomas T. S., Ponlok T., Bansok R., De Lopez T., Chiang C., Phirun N., Chhun C. 2013. « Cambodian Agriculture: Adaptation to Climate Change Impact. » SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2343170. Accessed July 2019.

Brouwer C., Heibloem M. 1986. « FAO Irrigation water management : training manual n°3 ». http://www.fao.org/3/s2022e/s2022e00.htm. Accessed August 2019.

Hecht J. S., Lacombe G., Arias M.E., Dang T.D., Piman T. 2018. « Hydropower Dams of the Mekong River Basin : A Review of Their Hydrological Impacts. » Journal of Hydrology 568 (May 2018): 285–300. https://doi.org/10.1016/j.jhydrol.2018.10.045.

Annex 1. *Interview grid for farmers, survey 08/19.*

BASIC INFORMATION	
Prek	
Name	
Phone number	
Age	
Gender	
Occupation	
For how long have you been cultivating in the area ?	
How many plots do you have ?	
Could you indicate your plots on the map ? Or could you lead me to your plots ?	

CROPPING SYSTEM		Crop ID	Crop Type	A	S	O	N	D	J	F	M	A	M	J	J	Production [kg]	Crop/yield losses ? (Y/N)	Losses reason (D,F,other)	For sale/for living	Market	Unit price (riel/kg)
Plot	Area [ha]	Irr calendar	Irrigation (Y/N)	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	Irrigation source	Irrigation frequency	Pumping time [h]	Pump characteristics : Q [m3/h]	Pump characteristics : HP [kW/h]	Pump characteristics ΔH [m]
Plot 1		Crop 1																			
		Irrigation																			
		Crop 2																			
		Irrigation																			
		Crop 3																			
		Irrigation																			
		Crop 4																			
		Irrigation																			
		Crop 5																			
		Irrigation																			
Plot 2		Crop 1																			
		Irrigation																			
		Crop 2																			
		Irrigation																			
		Crop 3																			
		Irrigation																			
		Crop 4																			
		Irrigation																			
		Crop 5																			
		Irrigation																			
Plot 3		Crop 1																			
		Irrigation																			
		Crop 2																			
		Irrigation																			
		Crop 3																			
		Irrigation																			
		Crop 4																			
		Irrigation																			
		Crop 5																			
		Irrigation																			
Plot 4		Crop 1																			
		Irrigation																			
		Crop 2																			
		Irrigation																			
		Crop 3																			
		Irrigation																			
		Crop 4																			
		Irrigation																			
		Crop 5																			
		Irrigation																			
Plot 5		Crop 1																			
		Irrigation																			
		Crop 2																			
		Irrigation																			
		Crop 3																			
		Irrigation																			
		Crop 4																			
		Irrigation																			
		Crop 5																			
		Irrigation																			

If not enough information about pump : could you lead me to your pump ?	
Do you have unused wells in mind ? If yes : could you lead me to it ?	

Annex 2. Participatory map, preks Chann&Touch, survey 08/19.

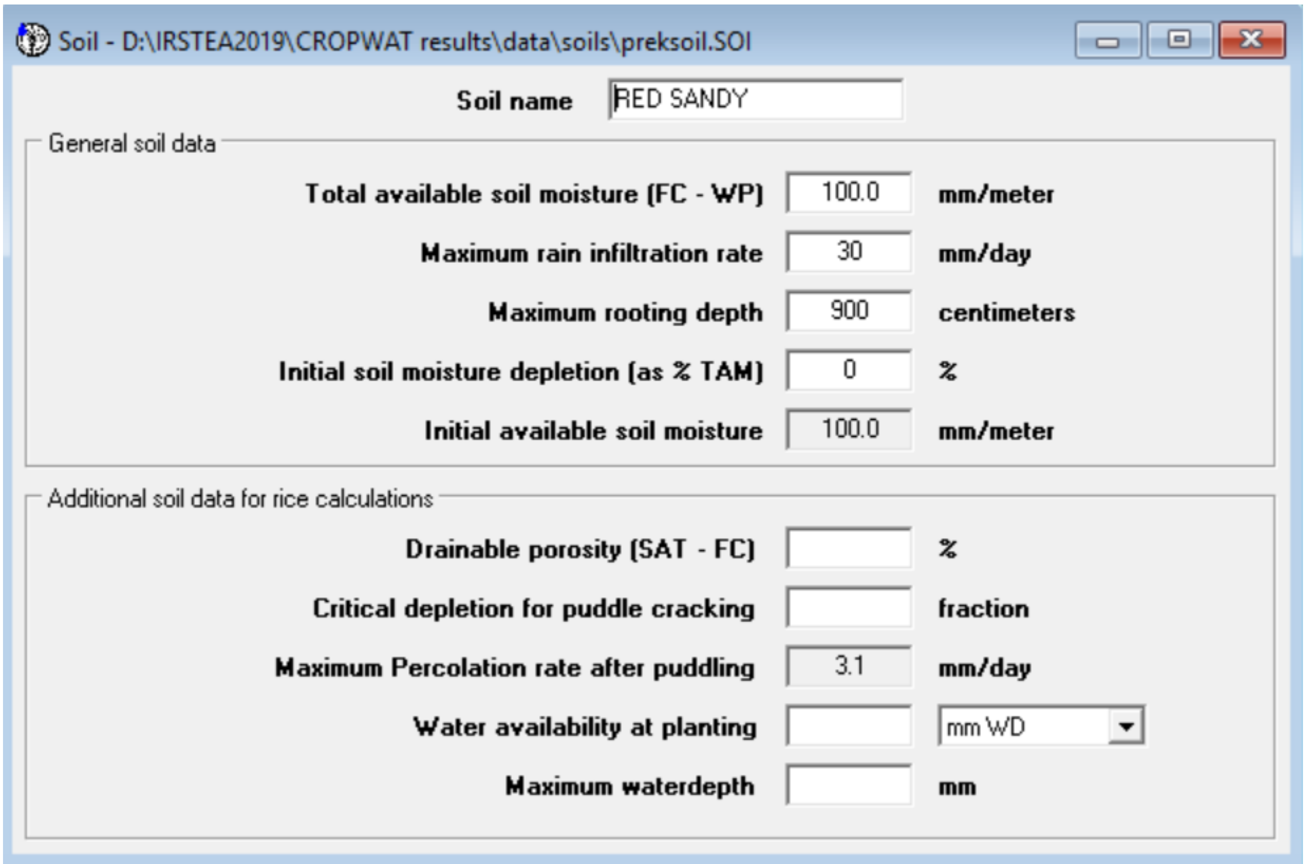
Annex 3. Monthly ETO Penman-Monteith computation, CROPWAT 8.0.

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

Country: Location 2 Station: PHNOM-PENH-POCHENTON
Altitude: 10 m. 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 4. Soil data input, CROPWAT 8.0.



Annex 5. Cropping pattern input, prek Chann, CROPWAT 8.0.

CROPPING PATTERN DATA
(File: C:\ProgramData\CROPWAT\data\sessions\prek-chann.PAT)

Cropping pattern name: Prek_Chann

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1	DS-RICE-1.CRO	DRice1	01/11	28/02	18
2	DS-RICE-2.CRO	DRice2	01/01	30/04	40
3	WS-RICE.CRO	WSrice	01/08	08/11	17
4	DS-EWS maize.CRO	DSmaize	01/04	29/06	2
5	WS-Maize.CRO	WSmaize	01/06	29/08	3
6	WS-Maize.CRO	WSmaize	01/09	29/11	3
7	SOYBEAN-dsvege.CRO	Soybean	15/11	07/02	9
8	wsVEGETABL.CRO	Small Vegetables	01/05	03/08	4
9	wsVEGETABL.CRO	Small Vegetables	10/08	12/11	4
10	mango.CRO	MANGO	01/01	31/12	10