# RICE MAP AND AREA ESTIMATES OF RICE CULTIVATION FOR THE MONSOON SEASON OF 2021

## Myanmar Agricultural Crop Yield Estimation Project

APRIL 2022

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**Submitted To**
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DISCLAIMER
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**Contract No**.10437-10-TIGA-21_01_ ADPC.

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# ABREVIATIONS

| | |
|---|---|
| ADPC | Asian Disaster Preparedness Center |
| CEO | Collect Earth Online |
| CSO | Central Statistical Organization |
| EVI | Enhanced Vegetation Index |
| FAO | Food and Agriculture Organization |
| FAS | Foreign Agricultural Service |
| GAD | General Administration Department |
| GAIN | Global Agriculture Information Network |
| GEE | Google Earth Engine |
| IFPRI | International Food Policy Research Institute |
| IRRI | International Rice Research Institute |
| LULC | Land Use Land Cover |
| MOAI | Ministry of Agriculture and Irrigation |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MRF | Burma Rice Federation |
| MRSDS | Burma Rice Sector Development Strategy |
| NDVI | Normalized Difference Vegetation Index |
| NDWI | Normalized Difference Water Index |
| NICFI | Norway's International Climate and Forests Initiative |
| RLCMS | Regional Land Cover Mapping System |
| SAR | Synthetic Aperture Radar |
| USDA | United State Department of Agriculture |
| USGS | United State Geological Survey |

# EXCLUSIVE SUMMARY

Food security is a major concern in Burma because of the pandemic, the political and economic situation and climate. Rice is the country's primary agricultural product, which is produced mainly for domestic consumption but also for export (representing now roughly 4 percent of global rice exports). In this report we use remote sensing technologies to analyze the area and productivity of monsoon paddy rice production in 2021 in Burma. We focus on the 9 most important rice producing regions and states – Sagaing Region, Bago Region, Magway Region, Mandalay Region, Mon State, Rakhine State, Yangon Region, Shan State, and Ayeyarwady Region.

The assessment consisted of two phases. The first was a mapping and validation exercise to determine the extent of monsoon rice paddy cultivation in the eight areas. We then inferred rice yield and production from these areas by investigating: (1) trends in the weather compared to previous years; (2) comparing the vegetation response rates of 2021 to previous years; and (3) assessing mapped area with historical information on crop area, crop yield and crop production and the result of the rice productivity assessment by the International Food Policy Research Institute (IFPRI), also conducted with support from USAID.

A machine learning method using multiple satellite data has been used for mapping the rice cultivation for the monsoon season in 2021 in Burma. A total area of 4.8 million (+/- 0.6 million hectares (ha) of rice planted for the 2021 monsoon rice season was estimated.

Our estimates of the area planted in rice is slightly lower compared to the statistical yearbook and USDA estimates, but are in line with the Burma government's historical General Administration Department (GAD) data. Overall, rice maps of these nine states and regions have achieved overall accuracy of above 95%.

There are many variables that influence how productive these rice fields are, including weather and fertilizer application. Therefore, we assessed trends in weather conditions during 2021 that may affect productivity of these agricultural lands. The results show that weather conditions were generally favorable throughout the country, with an exception for Sagaing and Shan which received below average rainfall.

The vegetation index analysis showed that rice crops appeared on average greener than the previous 10 years, with an exception for conflict areas in Sagaing which showed negative trends.

We preliminarily estimate 14,383 thousand tons (+/- 2005) kg of rice production being produced in the 2021 monsoon season. That report a slight reduction in production compared to the 2020 USDA estimate and a large decrease from the production reported by the yearbook, but higher than the GAD data. Production at the state level shows reductions at all nine states, and more profound in Sagaing, Mon, Yangon, Mandalay and Bago.

Differences in reported production are mostly influenced by the reported yield estimates, which can vary greatly among different data sources. More information on the use of fertilizer in different parts of the country could help refine the total production estimates.

# 1. INTRODUCTION

Rice is Burma's most important agricultural commodity. Both small and large farms in Burma produce monsoon paddy as their main crop (World Bank, 2016), though Burma rice production has fluctuated substantially in recent years, over 27 million tons produced in 2019 (CSO, 2020), and Myanmar accounted for more than 13 million metric tons of milled production in this year (USDA, 2020). The largest rice-producing area in Burma is in the Ayeyarwady Delta. According to the Department of Agriculture, the Ayeyarwady, Bago, and Yangon Regions make up more than half of the country's harvested rice area (USDA, 2019). Burma's major rice ecosystems include rainfed lowland rice, irrigated lowland rice, deep water rice, and upland rice.

In 2020, COVID-19-related restrictions directly impacted cash flow in supply chains, with agricultural firms facing cash flow shortages and diminished access to credit, creating greater vulnerability to economic crises. Another indication of the impact of COVID-19 on cash flow is the higher number of customers who asked to purchase using credit, particularly in the Shan and Rakhine states and Yangon region (World Bank, 2021). Sixty-nine percent of vendors reported facing a moderate to strong reduction in sales. Overall, COVID-19 and political problems due to the military take-over have hit the agri-food sector of Burma hard, raising doubts on the performance of the agricultural sector overall and the rice sector in particular (MAPSA 2021c, Goeb et al. 2021, Boughton et al. 2021).

According to the World Bank, agriculture sector activities are expected to contract by around eighteen percent in the 2021 fiscal year (World Bank, 2021), which is likely to have severe impacts on food security, particularly for the large number of poor people living in rural areas mainly due to the COVID-19 pandemic and also the political crisis in Burma. Farmers have already been affected by (i) declining incomes because of lower farm gate prices for some produce (especially perishable items like tomatoes and onions); and (ii) higher prices for key inputs such as fertilizer, fuel, seeds, and equipment, as well as food items of which they are net buyers (such as cooking oil, as well as rice in certain regions). Reduced incomes and higher costs are likely to have adverse impacts on consumption and food security for farmers and, in combination with financial constraints and output market uncertainties, are also reducing the ability of farmers to invest. Economically, non-farming incomes have also weakened, with analysis showing that a substantial rise in food insecurity in Burma has been driven more by income declines than reductions in food production. In this regard, this report focused particularly on the production of rice in the 2021 monsoon cycle.

Crop yield monitoring is important for assessing national food security and for providing timely information for the optimum management of growing crops. Changes in environment parameters can have an enormous influence on crop growth and development, resulting in year-to-year and location-to-location variations in crop yields. Therefore, crop monitoring and forecasting provides indispensable information on the status of a country's food security, including informing policy decisions as well as providing farmers with accurate yield forecasts that can contribute to better planning and crop scheduling.

Current information on crop production is urgently needed in Burma. Planners, policymakers, and other actors need accurate crop production information for key crops to understand how estimates compare year-on-year. Multiple current events, including a major COVID-19 outbreak and the ongoing social and economic disruption, have the potential to reduce crop yields and threaten national and regional food security.

## 1.1 OBJECTIVES

Timely development of country-wide crop production estimates is needed in Burma for food security planning and policy-making, using methods that do not require fieldwork given the limited availability of up-to-date and accurate data from government sources and the difficulty for any group to move around Burma to gain on-the-ground inputs. To fulfill this need, we use remote sensing, mathematical models, historical statistical data and available complementary recent data survey, especially from IFPRI to estimate the production of crops in Burma for 2021. Specifically, the study has the following objectives:

- Estimate the area of land currently in rice cultivation using satellite-based remote sensing data, machine learning mapping algorithms, and high-resolution imagery for image interpretation.
- Investigate factors related to yield and productivity using historical trend analysis of satellite-based data, published literature, and historical yield data.
- Build a foundation for conducting advanced levels of yield estimation in the future.

This report contains:

1. An in-depth analysis of climate and vegetation factors for the 2021 monsoon season.
2. Area estimates (in hectares), including uncertainty levels, of rice cultivation for nine selected rice cultivating regions in Burma for the 2021 monsoon season.
3. Rice production estimates, with uncertainty levels for those selected regions in Burma.
4. Recommendations for higher accuracy of rice area, yield, and production estimates.

## 1.2. FOCUS REGIONS AND CROPPING SEASONS

Burma's major rice ecosystems include rainfed lowland rice, irrigated lowland rice, deep-water rice, and upland rice. These types of rice ecosystems are distributed in three main ecoregions - the delta, coastal and dryland areas. According to Department of Agriculture (DOA) statistics, in the 2017 -2018 growing season, the Ayeyarwady region encompasses about 29 percent of total rice production, followed by the Bago region at about 17 percent, the Sagaing region at 13 percent and the Yangon region and Shan state at seven percent each (USDA, 2019). Therefore, we have selected nine states that exhibit the highest rice production in Burma. The nine regions and states for rice mapping are: Sagaing Region, Bago Region, Magway Region, Mandalay Region, Mon State, Rakhine State, Yangon Region, Shan State, and Ayeyarwady Region (See Figure 1).


*Figure 1. Regions and States for rice mapping in Burma*

Mapping the area of rice cultivation during the monsoon season in 2021 in Burma using satellite images is based on the crop calendar of the rice ecosystem in each state. Table 1 lists the period of planting and harvesting date for the monsoon season rice season in each state. Satellite information will reflect the change of vegetation phenology as rice grows during these specific periods for mapping.

*Table 1. ADPC's proposed regions and corresponding rice growing seasons for rice, maize and beans/pulses*

| **Rice Agro-ecological System** | **Planting** | **Harvesting** | **Focus Region** |
|---|---|---|---|
| Normal rainfed lowland and upland | May - June | November - December | **Delta Ayeyarwady** |
| Late rainfed lowland | July - August | November - December | **Bago; Yangon; Sagaing** |
| Deepwater | April - May | November - December | **Shan; Rakhine; Mon** |
| Main (receding) rice | October - November | February - March | **Mandalay** |
| Irrigated wet season | May - June | October - November | **Magway** |
| Irrigated dry season | November - December | April - May | |
| **Maize Agro-ecological System** | **Planting** | **Harvesting** | |
| Central dry zone and hilly regions | May - June | September - October | **Southern Shan, Nay Pyi Taw, Ayeyarwady** |
| Delta regions (Dry-season corn crop) | November - December | February - March | |
| **Beans and Pulse Agro-ecological System** | **Planting** | **Harvesting** | |
| Central dry zone and Shan State | May - June | August - September | **Ayeyarwady, Bago, Shan, Mandalay, Magway, Sagaing** |
| Delta region | November - December | March – April | |

# 2. METHODOLOGY

Three types of analyses were carried out to evaluate rice production during the 2021 monsoon season for Burma: (1) an analysis of the rice area; (2) an analysis of climate; and (3) an analysis of the vegetation health. All data and analysis were conducted in Google Earth Engine (GEE).

## 2.1 RICE AREA ESTIMATES

Rice area estimates were derived from an inventory of image-interpreted samples that were allocated using a stratified random sample based on a rice map. The map was generated using satellite imagery and a machine learning classification model. Figure 2 shows the overall workflow of this study. The method includes four stages: (i) satellite image preprocessing; (ii) seasonal crop mapping; and (iii) sample-based analysis for area of crop cultivation; and (iv) yield estimation and validation using available historical national statistical data. The paragraphs below describe the details of each section.

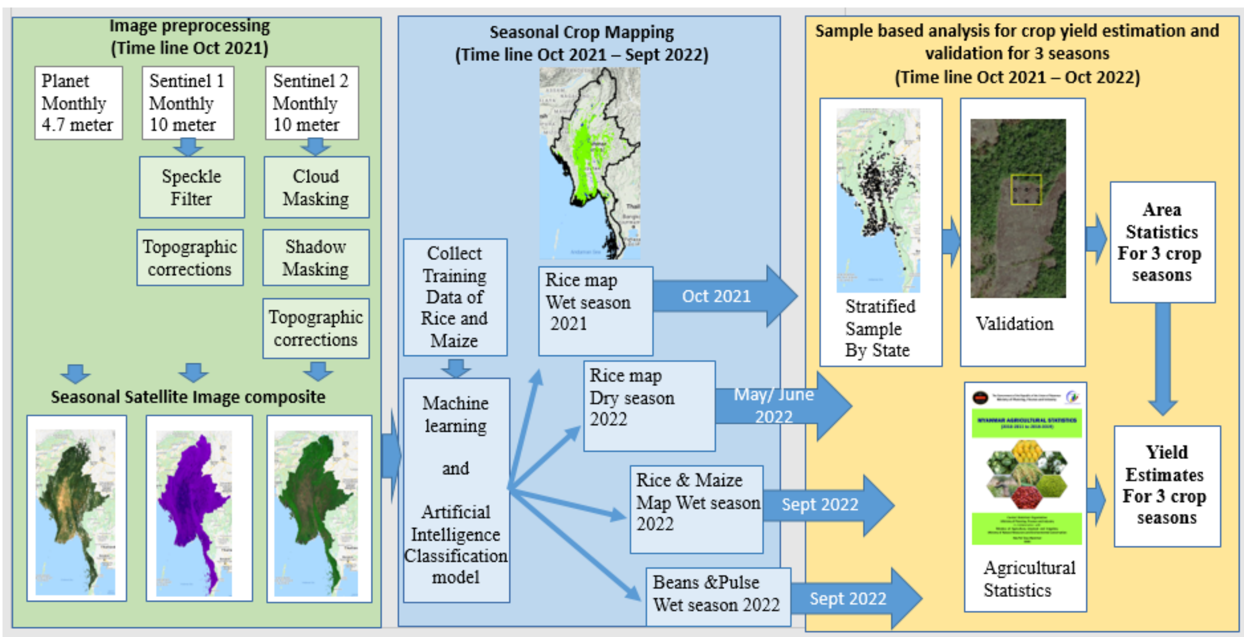
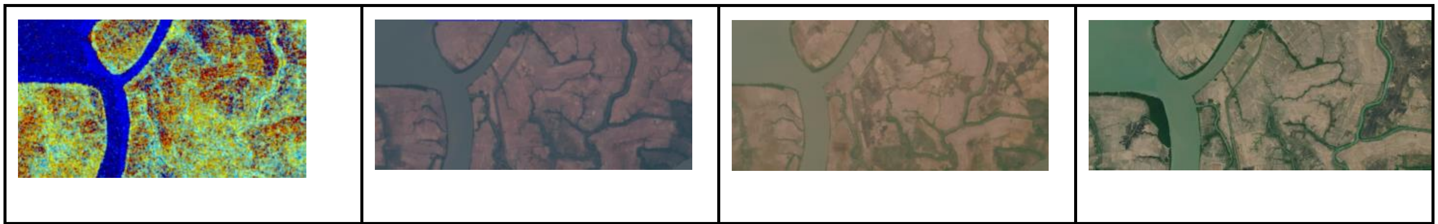



*Figure 2. An overview of the satellite image processing (left), the machine learning approach (middle), and the data validation (right) to estimate the crop production per state and region.*

### 2.1.1 Satellite Image Preprocessing

Satellite imagery from one active, synthetic aperture radar (SAR), and two passive, optical, satellite sensors were used to create the rice model and resulting map: Sentinel-1; Sentinel-2; and Planet, respectively (Figure 3). The Mapbox image available in the Collect Earth Online tool was used for image interpretation at sample locations to estimate area and validate maps.



| | | | |
|---|---|---|---|
| Sentinel 1 (10m) | Sentinel 2 (10m) | Planet (4.7m) | Map box (0.2m) |

*Figure 3. Examples of the three sources of satellite images and their spatial resolution. These imagery feeds were used for rice mapping (Sentinel 1 and 2 and Planet) and image interpretation at sample locations (Map box).*

The European Space Agency's (ESA) Copernicus Sentinel-1 mission provides (SAR) images with high temporal (6 days) and spatial resolution (10m). We use both polarization bands, which are the *VV* and *VH* dual bands. These SAR images in GEE have already undergone thermal noise removal, radiometric calibration, and terrain correction. We apply additional processing, including a filter to de-speckle the image (Lee *et al*., 2009), and then harmonize and composite the individual images into monthly and/or seasonal images for further processing.

The ESA Copernicus Sentinel-2 mission provides high spatial resolution optical images (10-60m). The spatial resolution for Sentinel-2 varies for the different bands. The blue, green, red, and near-infrared bands have a resolution of 10 meters, the red-edge and shortwave-infrared bands 20 meters, and all others 60 meters. We use the Sentinel-2 image collection in GEE, which contains spectral bands representing Surface Reflectance from the Sentinel-2A and -2B satellites. Pre-processing steps for Sentinel-2 included shadow and cloud removal.

Planet Surface Reflectance base maps are available through Norway's International Climate and Forest Initiative (NICFI). These data have a spatial resolution of 4.77 meters and are available on a monthly basis for Burma. The Planet base maps are particularly suitable for crop-mapping analytics as it is pre-processed data that account for sensor characteristics, sun angle, spatial accuracy, and other artifacts caused by haze, light, and topography. The base maps are created from the PlanetScope satellite constellation. The 4-band PlanetScope imagery was corrected using the 6SV model (Second Simulation of the Satellite Signal in the Solar Spectrum-Vector version (Vermote et al., 2006)) in combination with Moderate Resolution Imaging Spectroradiometer (MODIS) data while accounting for sun angle and satellite view geometry.

### 2.1.2 Machine Learning Model for Mapping

A random forest machine learning model was used to create maps of rice production across Burma. GEE has a robust random forest algorithm that has been used successfully with SERVIR-Mekong's Regional Land Cover Monitoring System (RLCMS) and other projects (Saah *et al*., 2020; Poortinga *et al*., 2020). Examples of areas with and without rice production are used to train the model – examples are provided in the training data (described below. The GEE random forest algorithm has six parameters: number of classification trees; number of variables used in each classification tree; minimum leaf population; bagged fraction of the input variables per decision tree; out-of-bag mode; and random seed variable for decision tree construction. Based on previous studies of the region (Poortinga *et al*., 2020), the algorithm's default settings work well with an increase in the number of trees to 100. The random forest implementation applies majority voting for all trees for class prediction by default. In probability mode, the fraction of trees that vote for a certain class are calculated.

### 2.1.3 Training Data

Training samples of rice were collected from high-resolution satellite images. National and local information on rice-growing areas and their crop calendars informed the collection of these samples. The historical paddy field area, land preparation (plowing, flooding method, etc.), stages of rice growth, and harvest time were observed from historical images as well as bi-weekly and monthly temporal images during the respective cropping season.

Training samples include samples with rice, deep water rice, and non-rice. Since rice cultivation practices vary across the country, samples were collected separately for each state/region to ensure coverage of the different types present in each study area. Deep-water rice samples were also collected, independent of normal rice. The training samples for non-rice (forest, urban, water, other crops, etc.) were extracted from SERVIR-Mekong's existing land cover maps from the RLCMS, national data, and a few newly added samples of locations where changes were observed. The amount of training data used for mapping rice in each state/region is detailed in Table 2 below.

*Table 2. Number of training data points used in the study for rice mapping.*

| Sr. No. | State and Region | Number of Rice Samples | Number of Non-rice Samples |
|---|---|---|---|
| 1 | Ayeyarwady | 12,603 | 13,260 |
| 2 | Bago | 2,034 | 2,997 |
| 3 | Magway | 3,794 | 5,327 |
| 4 | Mandalay | 2,161 | 3,865 |
| 5 | Mon | 4,101 | 3,923 |
| 6 | Rakhine | 1853 | 3007 |
| 7 | Sagaing | 1,451 | 3,048 |
| 8 | Shan | 5,114 | 5,594 |
| 9 | Yangon | 3,200 | 4,782 |

### 2.1.4 Model Validation and Area Estimation

In the literature, the most common method for area estimation involves simply counting pixels associated with a mapped class and multiplying it by the pixel area to obtain the total area. Despite its popularity, systematic classification errors of this method can lead to measurement bias that misrepresent the true proportion of the area. In this study, we adopted an area-adjusted sample-based approach to estimate the area of coverage. More specifically, analysis of a stratified random sample was used to estimate the area and uncertainty of rice cultivation, using the map from the machine learning model (Olofsson *et al*., 2014). The minimum number of samples needed for each state was calculated based on the total area classified as rice cultivated in 2021, according to the variance formula (Cochran 1977, eq. 5.25) summarized in Equation 1:

$$n \approx \left(\frac{\Sigma W_i S_i}{S(\bar{O})}\right)^2$$

(1)

Where, $W_i$ is the mapped area of class *i*, $S_i$ the standard deviation of stratum *i,* and $S(\bar{O})$, the standard error of the target estimated overall accuracy.

Once the total sample size was confirmed, the sample size of each strata were allocated proportional to the corresponding mapped areas. This ensures all classes are sampled regardless of their size. Points were placed on the map within each stratum until desired sample size was achieved. The sample points were interpreted by a team of regional land cover experts using Collect Earth Online (CEO). They assessed land use and land cover using recent high-resolution Planet imagery (4.7 meter resolution) made available with funding from Norway's International

Climate and Forest Initiative (NICFI). Regional experts examined each point and assigned a land cover class independent of the model results, forming a *reference classification*. These values were then compared with the model output in a confusion matrix. From this, unbiased estimators were used to calculate estimates of the area of rice under cultivation in each state/region along with the associated estimates of accuracy and uncertainty of the area estimate (with a standard error of 0.02).

It is inevitable that mapped areas will exhibit some classification errors. This method quantifies the magnitude of classification error by using a stratified estimator and quantifies uncertainty in terms of sampling variability that can be accounted for. This is achieved by:

1. Extracting the mapped area of each class from the pixel count multiplied by the sensor's resolution;
2. From the confusion matrix, computing for each class: the user's accuracy, i.e. the extent of overestimation in area (errors of commission); the producer's accuracy, i.e. the extent of underestimation (errors of omission); and the overall accuracy;
3. Adjusting the areas from step 1 to account for the errors computed in step 2; and
4. Computing the standard error of the error-adjusted area estimate with a 90% confidence interval.

For the accuracy assessment of the rice maps, 30% of the reference data are used to validate the model. To evaluate the accuracy and Kappa, we calculated a confusion error matrix to the binary classification of the crop type model, as class 0 (other classes) and class 1 (crop type class - rice in this case). An example of a confusion matrix for binary classification of the 'rice' model is shown in Table 3 (TN = True Negative; FP = False positive; FN = False Negative, TP = True Positive).

*Table 3. Confusion matrix for binary classification map of rice.*

| | | | Predicted Class | |
|---|---|---|---|---|
| | | | **Positive** | **Negative** |
| **Actual Class** | **Positive** | Other (0) | True Positive (TP) | False Negative (FN) |
| | **Negative** | Rice (1) | False Positive (FP) | True Negative (TN) |

The accuracy of the model is calculated using the given Equations (2,3) below.

$$\text{Overall Accuracy} = \frac{(TN+TP)}{(TN+FP+FN+TP)} \qquad (2)$$

$$\text{Overall Accuracy} = \frac{Total\ number\ of\ correctly\ classified\ samples}{Total\ number\ of\ reference\ samples\ chosen} \qquad (3)$$

Kappa statistics reflect the difference between the actual agreement and the agreement expected by chance. For example, Kappa of 0.58 of a model means a 58% better agreement than by chance alone. The formula to calculate Kappa is shown below (Equation 4). Observed accuracy is determined by the diagonal in the error matrix.

$$\widehat{K} = \frac{Observed\ accuracy + Chance\ agreement}{1 - Chance\ agreement} \qquad (4)$$

The overall accuracies and Kappa value of each model are shown in Table 9, Section 3.1.1 of this report).

## 2.2. ESTIMATING YIELD AND PRODUCTION

Crop yields cannot be estimated from remote sensing imagery with high accuracy. As such, we have to rely on historical accounts on crop yield and cross combine this information with other climatic and crop factors, or where possible, we complement this approach with other relevant estimates (estimates from a recent survey by IFPRI in Burma). Thus, we use data on crop yield from various sources, and combine these numbers with area estimates.

### 2.2.1 Historical Statistical Data

To convert our estimates of area under rice cultivation to yield and production, we use available historical data. We compiled data from four different sources as shown in Table 4. All sources present information on area, yield, and production. These sources are described in greater detail in the sections that follow.

We align the rice area and historical information to estimate production by multiplying crop area with respective yield in each region. According to the USDA production report, the yield estimate for the monsoon rice season is 2,800 tons per hectare (USDA, 2019). The Yearbook and GAD data, reported historical monsoon yield values by state/region, where the values for GAD were aggregated to a state/region level using data collected at the township level. We also included crop yield estimations from the IFPRI study to estimate rice productivity in Burma in 2022 (IFPRI, 2022). Their estimates are based on a sub-sample of 12,100 households interviewed by phone during the first round of the Burma Household Welfare Survey (MHWS) in the beginning of 2022.

There are some challenges to using historical data to estimate yields. For example, two of the datasets produced by the Government of Burma contain annual crop information on a country level. The Statistical Yearbook produced by the Central Statistical Organization (CSO) dataset presents information on the State and Region level, and the data published by the General Administration Department (GAD) has information at the township level, which can be aggregated to the state/region level. Therefore, we only use the data available at the sub-national level to estimate yields, but we do compare these with the national estimates for context.

The final challenge we face in estimating yield and production is related to temporal misalignment. We pair estimates of production and yield prior to 2021 with estimates of rice crop area from 2021. Information from IFPRI provides an estimate for 2021, but analysis of climate and vegetation data can also be used to help indicate if a reduction in yield could be expected due to environmental conditions.

*Table 4. Different sources of information for rice area, yield, and production.*

| Data Source | Variables | Spatial Coverage | Temporal Coverage |
|---|---|---|---|
| Statistical Yearbook, DALMS and CSO | Area, yield, and production | Country level as well as State/Region level | Yearly (2015 - 2020) |
| Township profile, GAD | Area, yield, and production | Township level | Seasonal (2020) |
| USDA | Area, yield, and production | Country level | Yearly (2018 - 2022) |
| FAO/IRRI | Area, yield, and production | Country level | Yearly (1995 - 2010) |
| International Food Policy Research Institute (IFPRI) | Yield and production | Country level as well as State and region level | 2021 |

*Central Statistical Organization*

The Burma Statistical Yearbook is produced by the Central Statistical Organization (Government of Burma). The Burma Department of Agricultural Land Management and Statistics (DALMS) publishes annual information on sown rice, harvested area, and rice production at the country, state, and regional levels. DALMS collects seasonal data for crops, e.g. cereals, oilseeds, pulses, etc., and aggregates them into State and Region levels and then into the Union level.

The information reported in the Yearbook covers a two-year time step, and has a data collection and reporting lag of one year. For example, the latest information available at the time of this early reporting is the 2021 Statistical Yearbook and it contains information on the 2019-2020 crop calendar year. These national statistical data are used for the estimation of rice production. Figures 4, 5 and 6 represent rice sown area, rice harvest area and rice production for six years from the Yearbook, covering a temporal time span from 2015-2016 to 2019-2020.

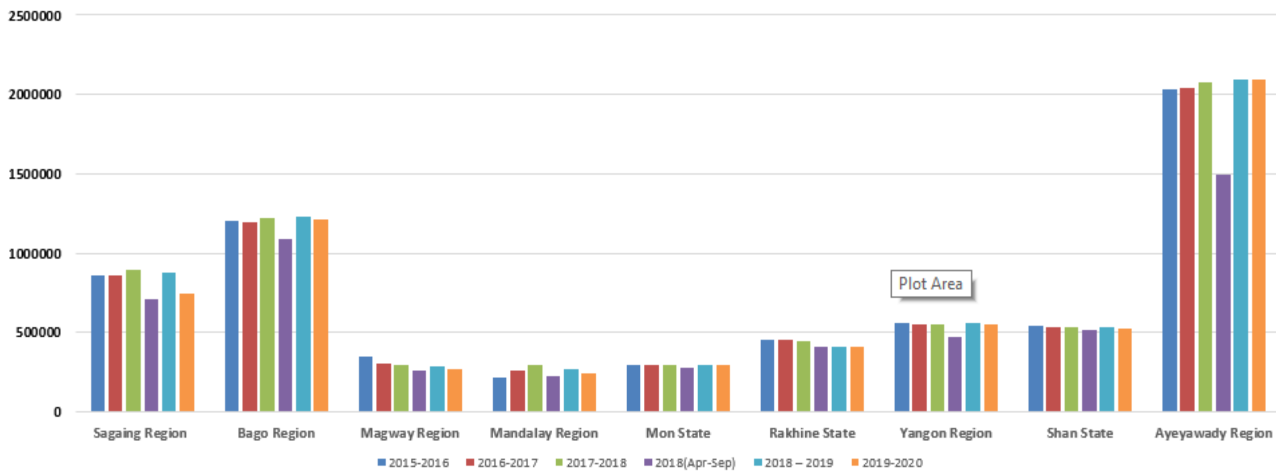



*Figure 4. Rice sown area from 2015-2016 to 2019-2020 for different States and Regions in Burma.*

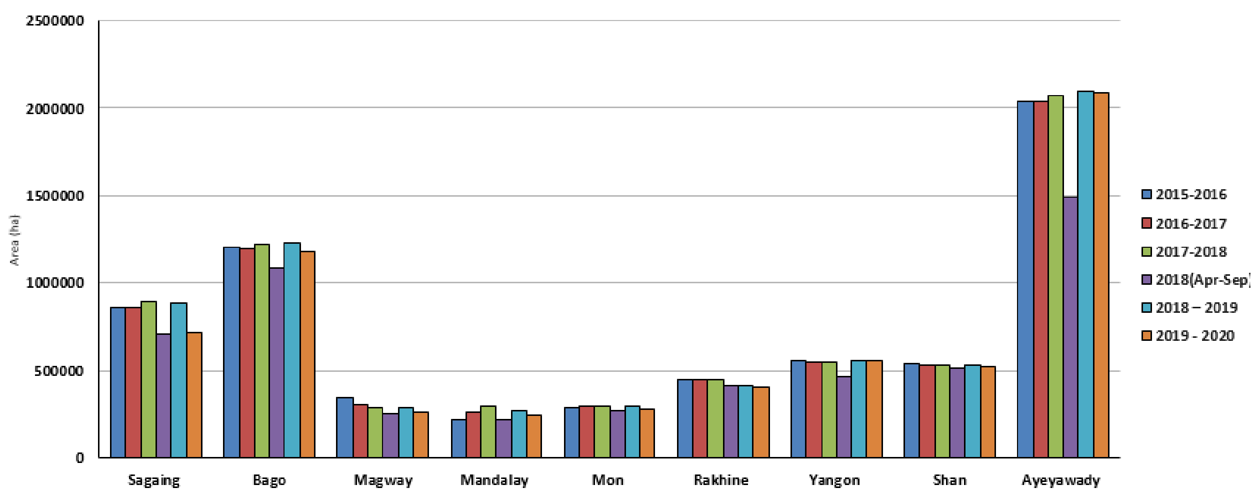



*Figure 5. Rice harvest area from 2015-2016 to 2019-2020 for different States and Regions in Burma.*

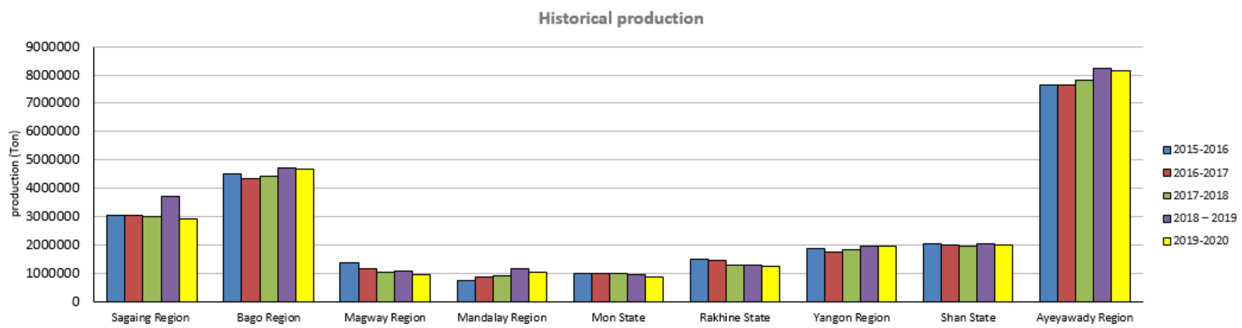



*Figure 6. Rice production from 2015-2016 to 2019-2020 for different States and Regions in Burma.*

### *Township Profile Data from the General Administration Department*

Township profile information is produced annually by Township General Administration Departments (GAD) for each township in Burma. The data were collected from the respective government departments; i.e. for crop, the data source is from the township agriculture department. In the agriculture section of the booklet, there is information about the target cultivation area, sown area, harvested area, crop yield, and crop production of ten major crops for each township. This includes information for cereals, oilseeds, pulses, etc. Most of the data are available seasonally at the township level. The latest information available for this reporting period is for the year 2020.

### *Comparison of Estimates between Burma Data Sources*

To compare the two historical government data sources, the CSO Yearbook and GAD, we analyze data at different administrative levels in Figure 7 and Figure 8 below to represent GAD's rice cultivation area and rice production for 2020. The charts show data agreement in most of the states/regions; some estimates between these two Burma data sources are quite close, however there are some substantial discrepancies for some of the states/regions, especially with regard to production in Sagaing Region, Shan State and Yangon Region.

Discrepancies in the data were further investigated using the GAD township information. A comparison in ADPC's aggregated remote sensing derived rice area estimates with the reported township information provides valuable information on the agreement between the two data sources. Machine learning models are very effective on mapping specific land cover types using spectral and temporal information from the satellite imagery, but sometimes confusion occurs when signals look similar. By comparing our rice estimates with the reported numbers at the township level, we are able to detect disagreements on a low administrative level and do a more thorough investigation on possible misclassification. Where the remote sensing data and GAD data disagree, a spatial analysis can be performed on areas with potential model biases or misreporting. Conducting the analysis on a small administrative unit such as the township level will help identify potential issues on a small spatial scale, whereas aggregation on larger spatial scales should lead to more accurate estimations.

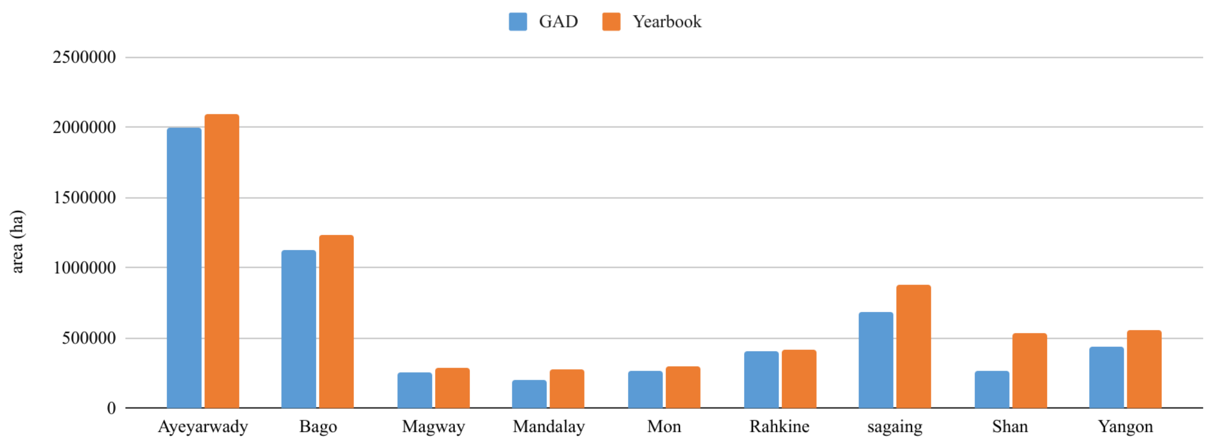



*Figure 7. GAD's rice cultivation area for 2020 for different States and Regions compared with the CSO Statistical Yearbook (2019-2020).*

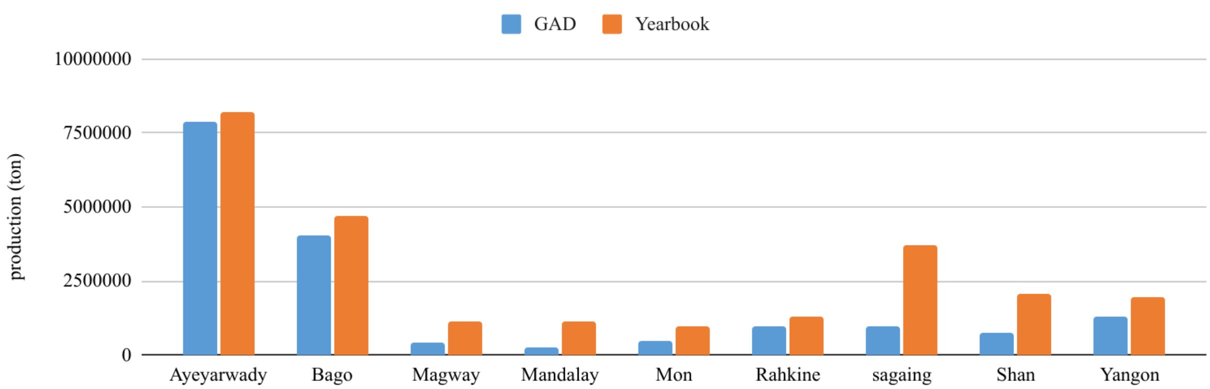



*Figure 8. GAD's rice production from 2020 for different States and Regions compared with the CSO Statistical Yearbook (2019-2020).*

### *Data Collected from the United States Department of Agriculture about Crop Production in Burma*

The United States Department of Agriculture (USDA)'s Foreign Agricultural Service (FAS) provides timely reports on foreign markets through the Global Agriculture Information Network (GAIN) database (Table 5). This report serves as a guide for U.S. companies seeking to carry out business in Burma by providing practical tips and information on local business practices, consumer preferences and trends, and import requirements. It highlights market trends within the retail food, food service, food processing, and livestock feed sectors and identifies U.S. agricultural product categories with growth potential in the Burma market. These data provide market information and are useful for crop yield and production estimation; however, the data are only available at the national level. There are no guidelines available that can be used to downscale yield and production estimates to the region or state levels.

*Table 5. USDA rice yield, harvest area, production and export in Burma*

| Elements | Unit | 2017/ 2018 | | 2018/2019 | | 2019/2020 | | 2020/2021 | | 2021/ 2022 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | USDA Official | Post Calculation | USDA Official | Post Calculation | USDA Official | Post Calculation | USDA Official | Post Calculation | USDA Official | Post Calculation |
| Rice yield | 1 tons/ ha | 2.9049 | 2.9269 | 2.8994 | 2.9131 | 2.9269 | 2.8646 | 2.8533 | 2.8953 | 2.8533 | 2.7971 |
| Harvest area | 1000 ha | 7100 | 7100 | 7100 | 7080 | 7100 | 6900 | 6900 | 6800 | 6900 | 7000 |
| Rough production | 1000 MT | 20625 | 20781 | 20586 | 20625 | 20781 | 19844 | 19688 | 19688 | 19688 | 19300 |
| Export | 1000 MT | 2750 | 2750 | 2500 | 2700 | 2700 | 2300 | 1900 | 1910 | 1900 | 2200 |

## *Data Collected by the International Food Policy Research Institute (IFPRI) on Crop Production in Burma*

The International Food Policy Research Institute (IFPRI) conducted a recent study to estimate monsoon rice production in 2021. The Myanmar Agricultural Performance Survey (MAPS) is a sub-sample of 12,100 households interviewed by phone during the first round of the Myanmar Household Welfare Survey (MHWS) that was conducted in the beginning of 2022 (MAPSA 2022a). In the MHWS, information was collected, among others, on the background of these households, welfare indicators, and livelihoods. 5,465 households were identified as crop farmers.

The results of IFPRI study on average and median yields of the largest rice plot are shown by state/region in table 6. The yield at the national level for the monsoon of 2021 was on average 1,289 kgs per acre (the median was 1,254 kgs per acre) or 3.1 tons per hectare, similar to estimates by USDA (2022) - they estimated rice yields at 2.8 tons per hectare for 2021.

*Table 6. Paddy rice yields on the largest plot, monsoon 2020 and 2021 (IFPRI, 2022)*

| State/ Regions | Yield Estimation 2020 | | | | Yield Estimation 2021 | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (kg/acre) | Median (kg/acre) | Mean (Tons/ha) | Median (Tons/ha) | Mean (kg/acre) | Median (kg/acre) | Mean (Tons/ha) | Median (Tons/ha) |
| Bago | 1,401 | 1,393 | 3.46 | 3.44 | 1,343 | 1,359 | 3.32 | 3.36 |
| Magway | 1,470 | 1,463 | 3.63 | 3.62 | 1,503 | 1,463 | 3.71 | 3.62 |
| Mandalay | 1,465 | 1,463 | 3.62 | 3.62 | 1,450 | 1,463 | 3.58 | 3.62 |
| Mon | 1,106 | 1,045 | 2.73 | 2.58 | 1,212 | 1,150 | 2.99 | 2.84 |
| Rakhine | 1,251 | 1,115 | 3.09 | 2.76 | 1,275 | 1,189 | 3.15 | 2.94 |
| Yangon | 1,198 | 1,115 | 2.96 | 2.76 | 1,172 | 1,069 | 2.90 | 2.64 |
| Shan | 1,172 | 1,045 | 2.90 | 2.58 | 1,165 | 1,045 | 2.88 | 2.58 |
| Ayeyawady | 1,201 | 1,045 | 2.97 | 2.58 | 1,142 | 1,045 | 2.82 | 2.58 |
| Sagaing | 1,404 | 1,393 | 3.47 | 3.44 | 1,406 | 1,393 | 3.47 | 3.44 |

## *Other Available Rice Productions Data Collection*

Data about rice production and cultivation in Burma in the past was also collected from other resources such as FAO (Table 5) and International Rice Research Institute (IRRI). These are also reported at the national scale, with no available guidelines on how to downscale estimates, and are more than a decade old. Therefore, these data are not used in the estimation but contribute to the understanding of past trends of rice yield and production in Burma and can provide an additional frame of reference for our final estimation.

FAO and IRRI have worked in collaboration with the Government of Burma. The statistical data that were published from these sources are similar to the trend of data from the CSO and GAD. The Government of Burma engaged with IRRI for technical assistance on the development and implementation of the Burma Rice Sector Development Strategy (MRSDS, 2015-2030).

*Table 7. Historical rice production from 1995 - 2010 (data published by FAO).*

| Element | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|
| Arable land (x$10^3$ ha) | 9,540 | 9,909 | 10,059 | 10,336 | 10,577 | 10,872 | 11,035 | |
| Rice area (x$10^3$ ha) | 6,033 | 6,303 | 7,384 | 8,074 | 8,011 | 8,078 | 8,000 | 8,052 |
| Paddy Yield (T/ha) | 2.98 | 3.38 | 3.75 | 3.83 | 3.93 | 4.03 | 4.09 | 4.12 |
| Paddy production (x$10^3$t) | 17,957 | 21,324 | 27,863 | 30,924 | 31,451 | 32,573 | 3,2682 | 33,205 |
| Rice export (x$10^3$t) | 354 | 251 | 180 | 71 | 359 | 222 | 250 | 122 |
| Total rice consumption (x$10^3$t) | 11,570 | 13,066 | 18,260 | 20,556 | 20,569 | 20,608 | 21,313 | |
| Fertilizer usage of fertilizer (kg/ha of arable land) | 19 | 21 | 7 | 9 | 16 | 7 | 5 | |

*Source: FAO's FAOSTAT database online and AQUASTAT database, as of September 2012 – published by IRRI*

### 2.2.2 Climate Trend Analysis

Rainfall is an important factor for rice production. Therefore, cumulative rainfall anomalies were computed. The dataset selected for this study was the Climate Hazards Group Infra-Red Precipitation with Station (CHIRPS) data, developed by the UC Santa Barbara Climate Hazards Center and supported by USAID. It offers more than 30 years of 0.05° resolution satellite imagery coupled with in-situ station data. Monthly rainfall averages were computed annually from 1981 to 2020 and used as a reference for calculating cumulative anomalies in 2021. The difference between the 5th and 95th percentile was also computed as an estimate of the outcome's uncertainty. The rainfall analysis is used to detect significant changes in rainfall in comparison to previous years that might negatively affect rice crop production.

### 2.2.3 Vegetation Health Trend Analysis

Vegetation indices are frequently used to monitor vegetation and crop health. In this study, the Enhanced Vegetation Index (EVI) was used to analyze crop health in relation to the historical record. The EVI is optimized for detecting vegetation signals in regions with high biomass and addresses the issue of Normalized Difference Vegetation Index (NDVI) saturation by reducing canopy background variations as well as atmospheric contamination (Huete *et al*., 2002). It enables the extraction of canopy biophysical parameters and allows for the monitoring of changes in vegetation in response to different stresses, such as varying rainfall patterns. This can be expressed by Equation 5:

$$EVI = \frac{(NIR - Red)}{(NIR + C1 \times Red - C2 \times Blue + L)} \quad (5)$$

Where *NIR*, *Red*, and *Blue* are atmospherically corrected surface reflectance bands, *L* is the canopy background term, and *C1* and *C2* are aerosol resistance terms.

In this study, two readily available EVI products from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor in GEE were selected: *Terra Vegetation Indices 16-Day Global 500m* and *Aqua Vegetation Indices 16-Day Global 500m*. The average monthly EVI of Burma's rice fields were mapped from 2010 to 2020 and used as a reference for computing cumulative anomalies in 2021. The cumulative anomaly shows the trend in EVI in relation to the baseline period. An increase means healthier vegetation, a decrease could indicate a worsening in the crop conditions which, in turn, could result in lower yields.

# 3. RESULTS

## 3.1 RICE AREA PLANTED

We estimate a total of 4.8 million (+/- 0.7 million) hectares of rice area planted across the 9 regions of interest. These estimates are based on both maps and a sample of plots that have labels from image interpretation. We break these estimates down by state and region in Table 8. The uncertainty number indicates the 90% confidence interval of our estimates (Tale 8 and Figure 9).

*Table 8. Area planted estimates per state and region*

| State and Region | Class Name | Our Estimate | Uncertainty |
|---|---|---|---|
| Ayeyarwady | Rice | 1,043,045 | 105,781 |
| | Deep water rice | 353,247 | 64,741 |
| Bago | Rice | 854,024 | 56,845 |
| | Deep water rice | 44,246 | 38,401 |
| Yangon | Rice | 362,050 | 21,545 |
| Rakhine | Rice | 364,220 | 28224 |
| Sagaing | Rice | 590,745 | 105,921 |
| Shan | Rice | 512,958 | 147,035 |
| Mandalay | Rice | 198,470 | 44,592 |
| Magway | Rice | 265,059 | 53,180 |
| Mon | Rice | 187,912 | 18,865 |
| **Total** | | **4,775,976** | **685,130** |

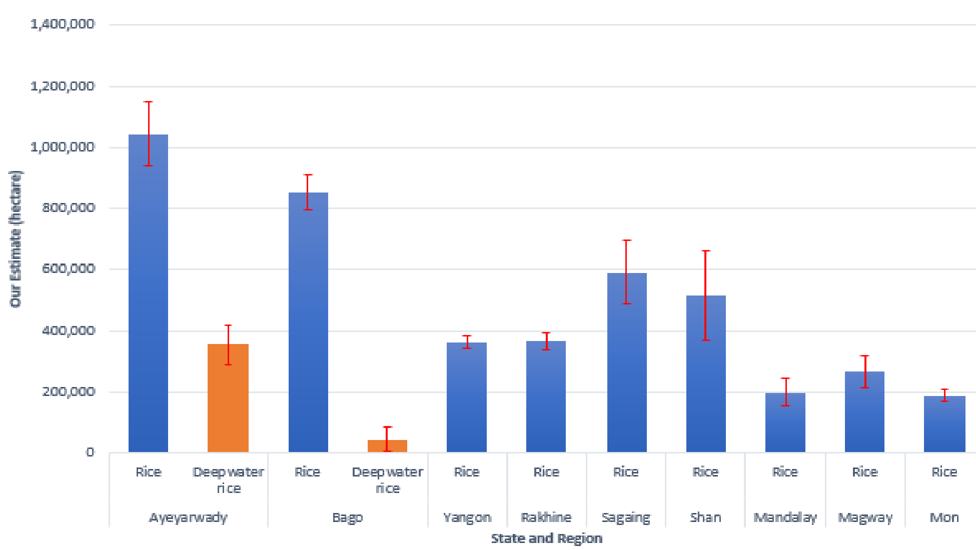
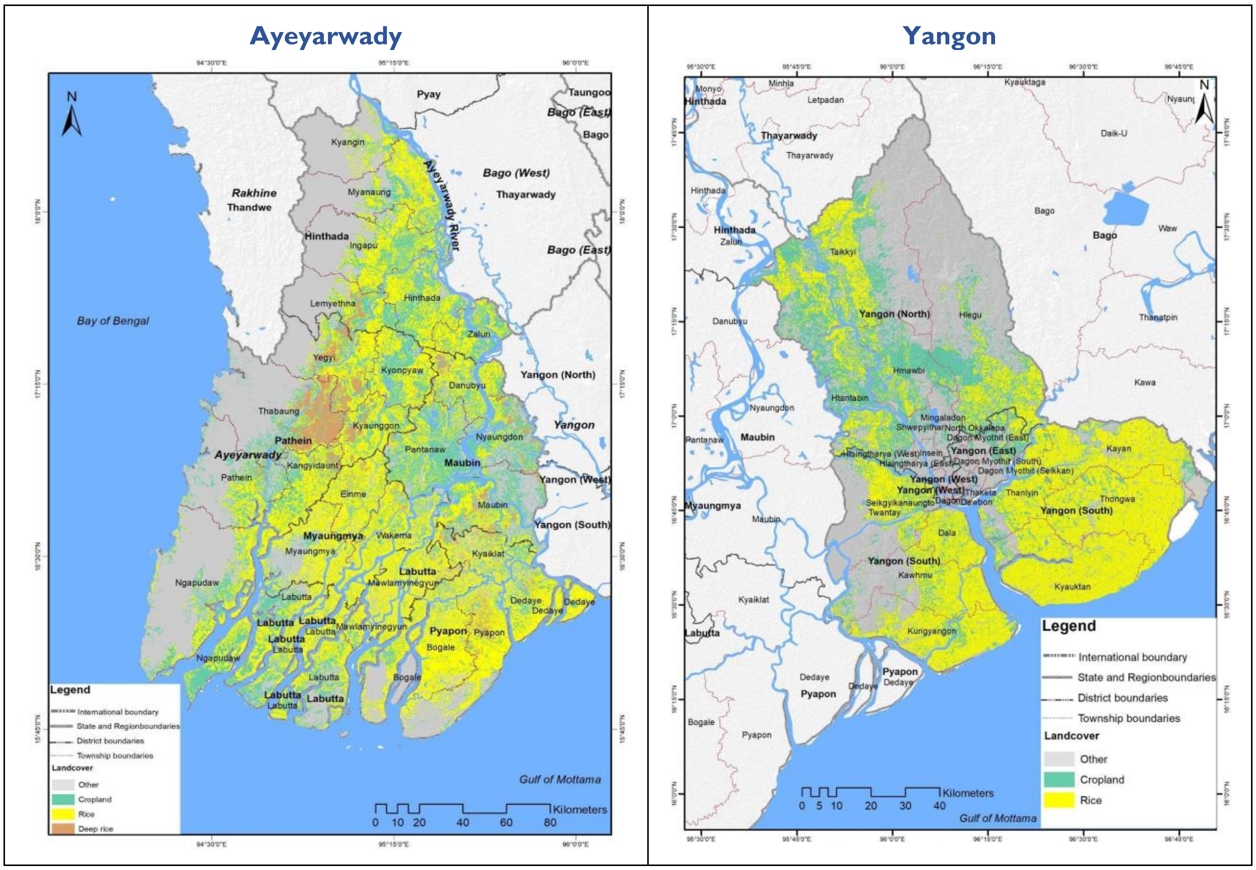



*Figure 9. Area planted estimates per state and region with 90% confidence interval*

## 3.1.1 Rice Area Estimation on Region/State Level

Rice growing state and region in Burma are in different terrestrial ecoregions, the maps for the ecoregion of lowland alluvial floodplain (Ayeyarwady, Yangon) and coastal zone (Mon, Rakhine) are shown in Figure 10. It can be seen that Ayeyarwady has areas covered with both rice and deep rice, whereas only rice was mapped for Yangon, Rakhine, and Mon. In Ayeyarwady and Yangon, rice can be found throughout the region and most of the rice field area was cultivated during the monsoon season in 2021; for Rakhine and Mon, rice fields are found in the area along the coast.



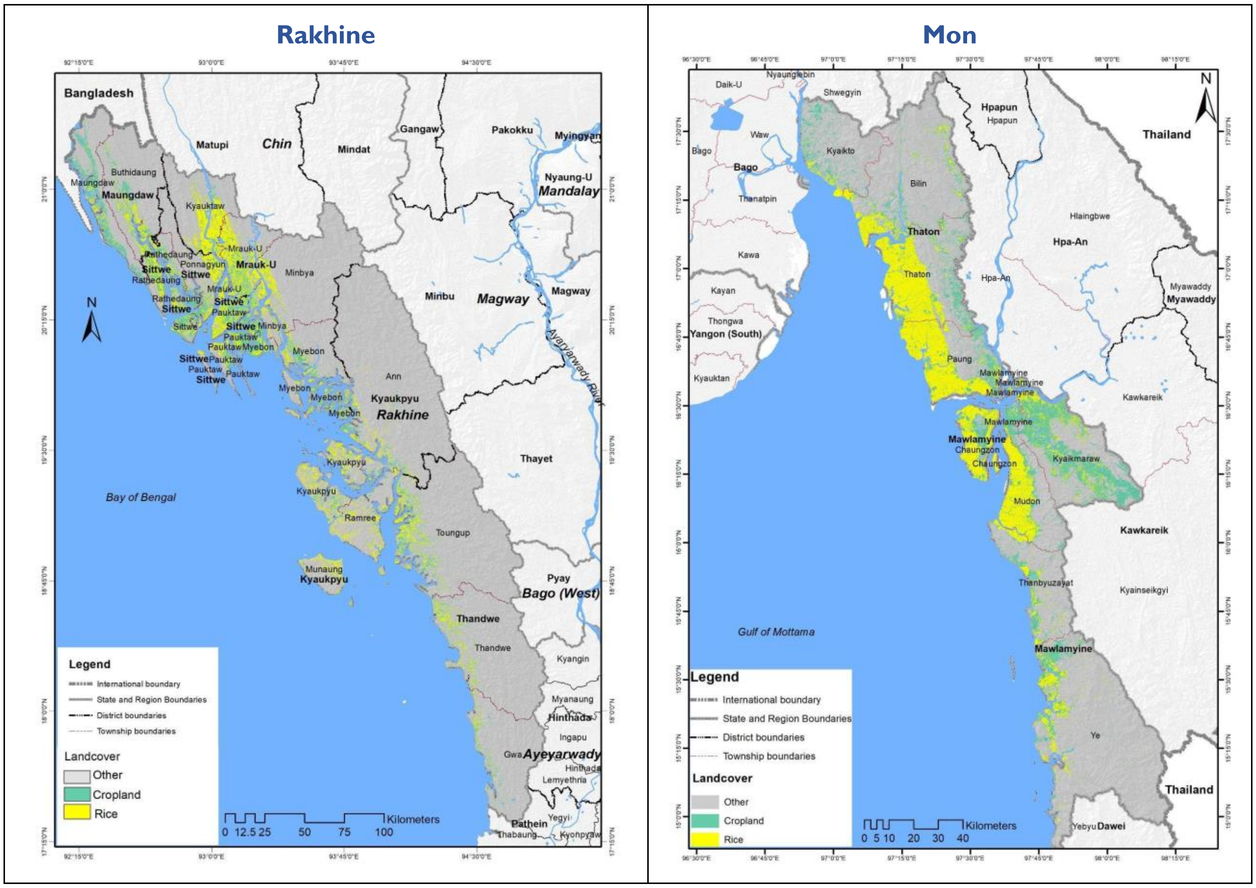



*Figure 10. Ayeyarwady (top left), Yangon (top right), Rakhine (bottom left), Mon (bottom right) for the 2021 monsoon season.*

The rice maps for the dryland regions including Bago, Magway, Sagaing and Mandalay state are shown in Figure 11. Rice can be found along the Ayeyarwady river in Bago and in close proximity are small areas with deep rice in Sagaing and rice fields in Mandalay. The portion of rice in relation to the total crop area is large in Bago, but much smaller in the other states.

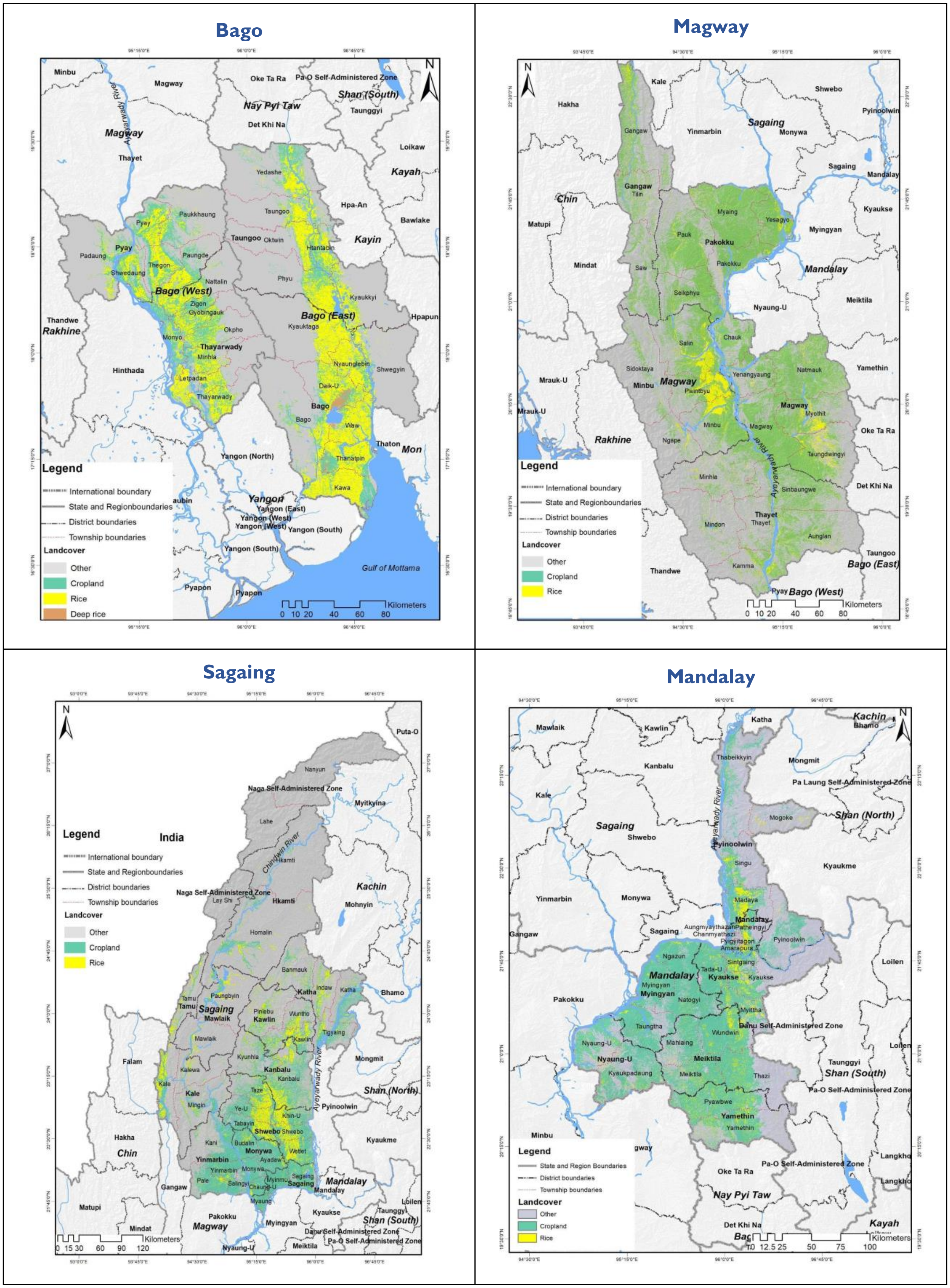



*Figure 11. Bago (top left), Magway (top right), Sagaing (bottom left), and Mandalay (bottom right) for monsoon season*

The rice and crop area in Shan are shown in Figure 12. Rice fields in Shan State can be found in the proximity of water. Rice represents a relatively small fraction of the total cropland area in Shan State compared to the coastal regions, for example.

**Shan**

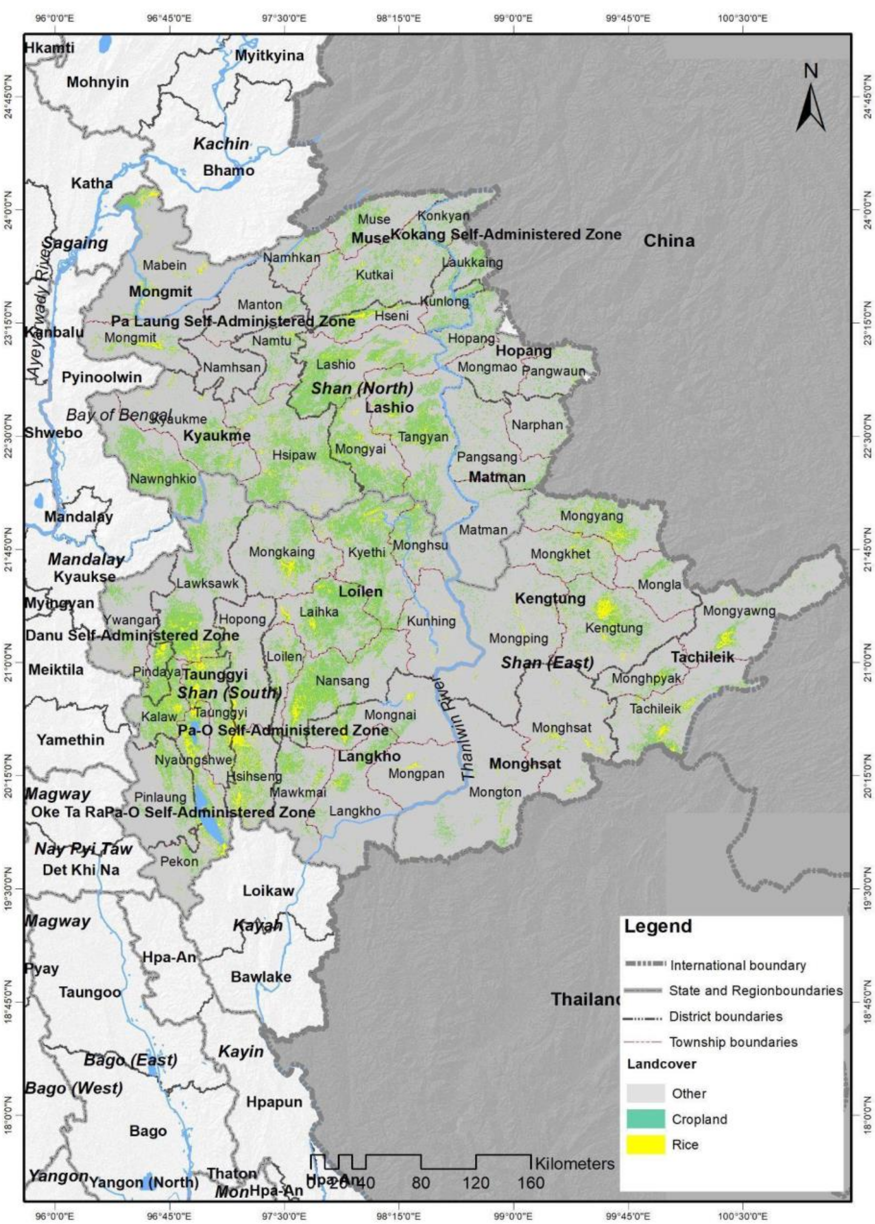



*Figure 12. Shan Rice Map of monsoon season (2021).*

## *Accuracy Assessment and Map Validation*

The rice map of each state and region was validated using the random stratified sample. The results of accuracy assessment by state/region shows that there was good agreement between the results from the machine-learning algorithm and the manual interpretation. The lowest accuracy was exhibited by Magway, and the highest for Shan and Ayeyarwady. Table 9 presents the overall accuracy and Kappa for rice and deep rice for each state and region. These agreement and error rates were used to determine the unbiased area estimates.

*Table 9. Accuracy for rice and deep-water rice in the different States and Regions*

| State and Region | Class Name | Overall Accuracy (%) | Kappa |
|---|---|---|---|
| Ayeyarwady | Rice | 0.98 | 0.96 |
| | Deepwater Rice | 0.94 | 0.83 |
| Bago | Rice | 0.97 | 0.94 |
| | Deepwater Rice | 0.99 | 0.99 |
| Yangon | Rice | 0.97 | 0.94 |
| Rakhine | Rice | 0.97 | 0.95 |
| Sagaing | Rice | 0.95 | 0.89 |
| Shan | Rice | 0.98 | 0.97 |
| Mandalay | Rice | 0.95 | 0.89 |
| Magway | Rice | 0.94 | 0.88 |
| Mon | Rice | 0.97 | 0.94 |

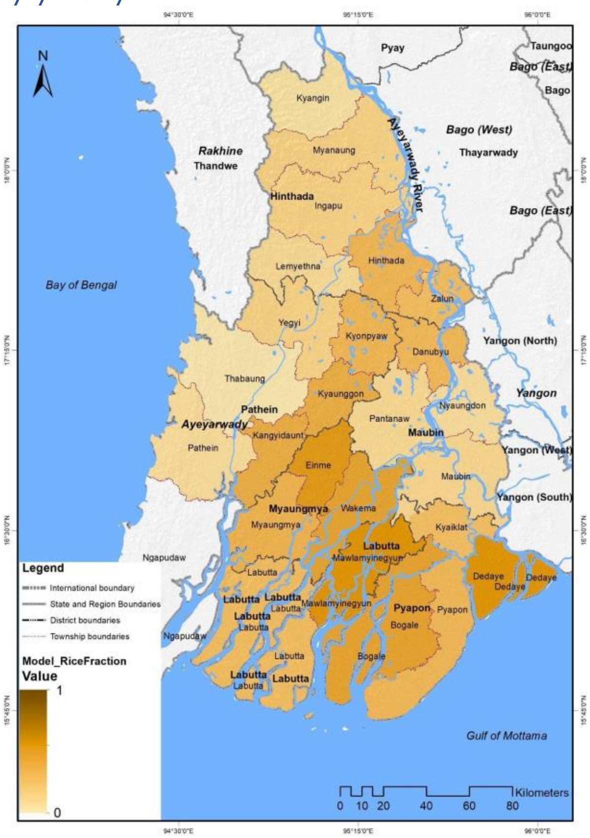
### 3.1.2 Rice Area Estimation at the Township Level

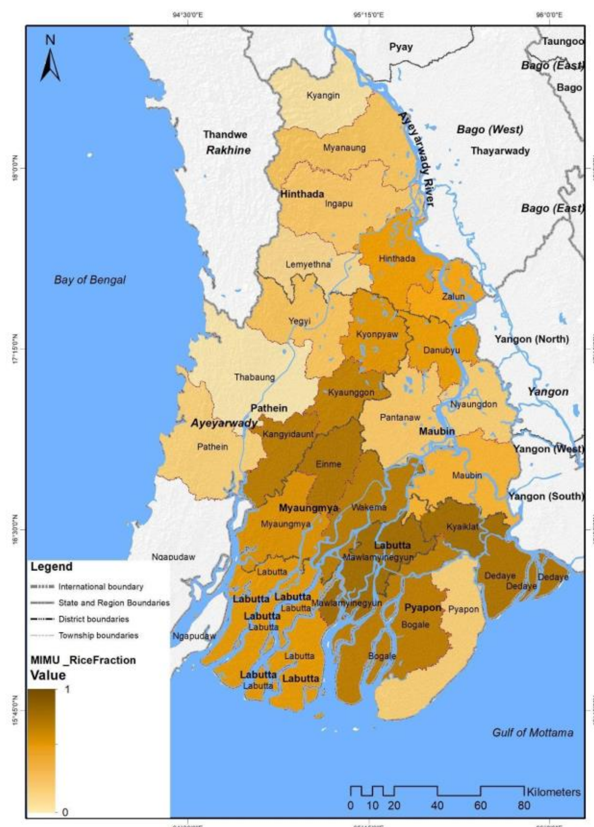
The rice maps were also overlaid with the township information. The township information was linked to the respective geospatial data and for each township the total rice area and rice area as a fraction of the total area was calculated. This data was then compared with the reported values, which were also calculated as a fraction of the total area. The results are shown in Figure 13.

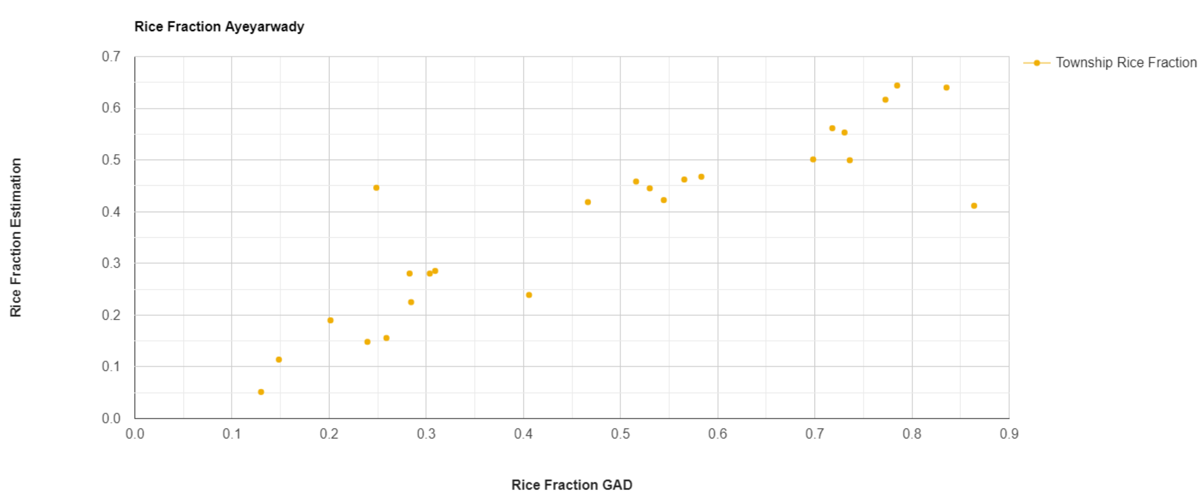
It can be seen that for the coastal states/regions there is generally a good agreement between ADPC's data and the numbers reported by the GAD. However, the southern townships in Ayeyarwady and northern townships for Yangon Region show a higher percentage coverage for the ADPC estimates compared to the GAD data. For the states and regions in the dryland zone, the greatest differences are found in Bago and Sagaing where the GAD rice fraction is higher than ADPC data. For Sagaing, the townships seem to correspond with areas that showed negative vegetation values. For Bago Region, the ADPC data have lower estimates for the townships in the southern and eastern parts. For Shan State in general, we found good agreement between the two maps. However, ADPC data have higher estimates for the townships in Shan State with the highest concentrations of rice cultivation.

| ***Model estimation: Area of rice fraction by township for monsoon season 2021*** | ***GAD's Township Profile data: Area of rice fraction by township in 2020*** |
| --- | --- |

Ayeyarwady



## Yangon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State and Region Boundaries
District boundaries
Township boundaries
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0
Kilometers
Gulf of Mottama
Yangon (North)
Taikkyi
Hlegu
Hmawbi
Htantabin
Yangon (East)
Yangon (West)
Yangon (South)
Kayan
Thongwa
Thanlyin
Kyauktan
Dala
Kawhmu
Kungyangon
Twantay


Legend
International boundary
State and Region Boundaries
District boundaries
Township boundaries
MIMU _RiceFraction
Value
1
0
Kilometers
Gulf of Mottama
Yangon (North)
Taikkyi
Hlegu
Hmawbi
Htantabin
Yangon (East)
Yangon (West)
Yangon (South)
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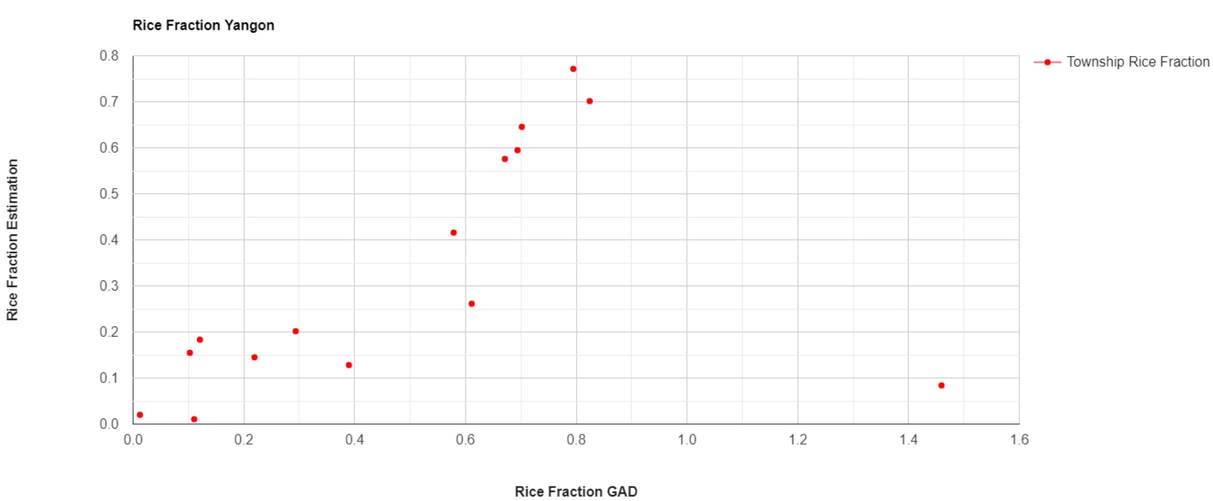
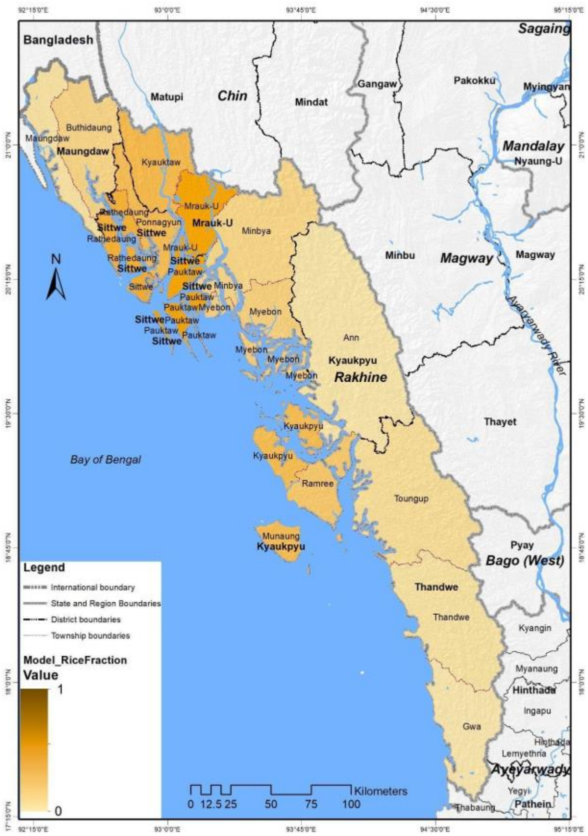
Thongwa
Thanlyin
Kyauktan
Dala
Kawhmu
Kungyangon
Twantay


Rice Fraction Yangon
Township Rice Fraction
Rice Fraction Estimation
Rice Fraction GAD

## Rakhine



Bangladesh
Chin
Sagaing
Mandalay
Magway
Rakhine
Bay of Bengal
Bago (West)
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District boundaries
Township boundaries
Model_RiceFraction
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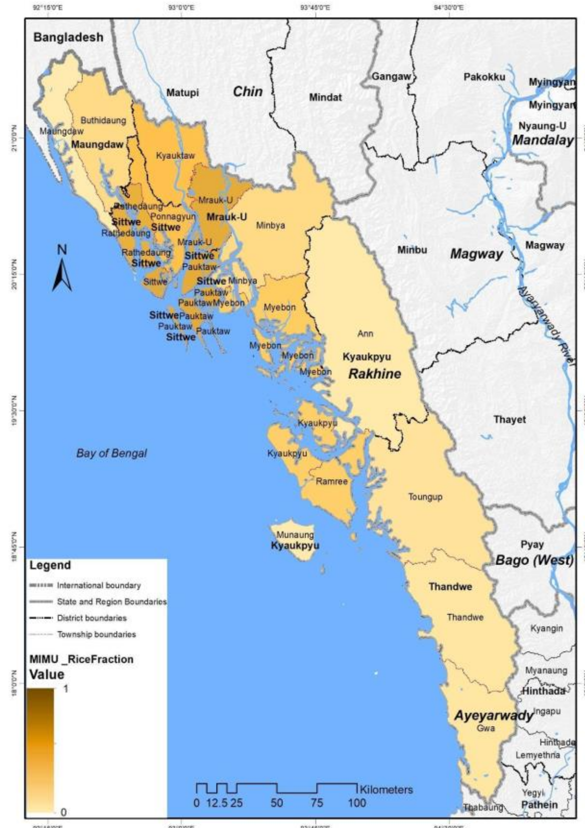
0 12.5 25 50 75 100 Kilometers

Bangladesh
Chin
Mandalay
Magway
Rakhine
Bay of Bengal
Bago (West)
Ayeyarwady
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State and Region Boundaries
District boundaries
Township boundaries
MIMU _RiceFraction
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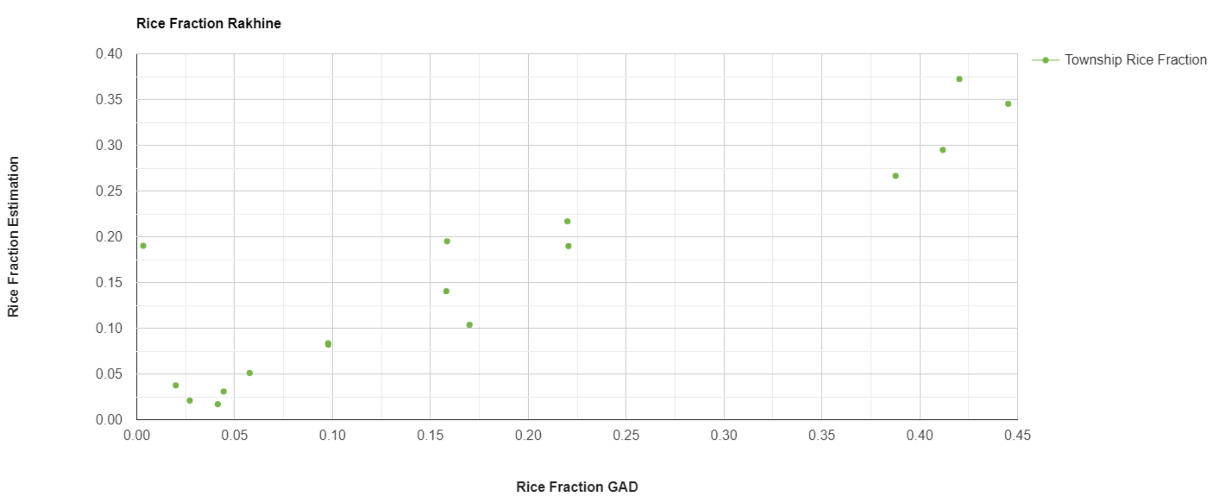
0 12.5 25 50 75 100 Kilometers

Rice Fraction Rakhine
Rice Fraction Estimation
Rice Fraction GAD
Township Rice Fraction
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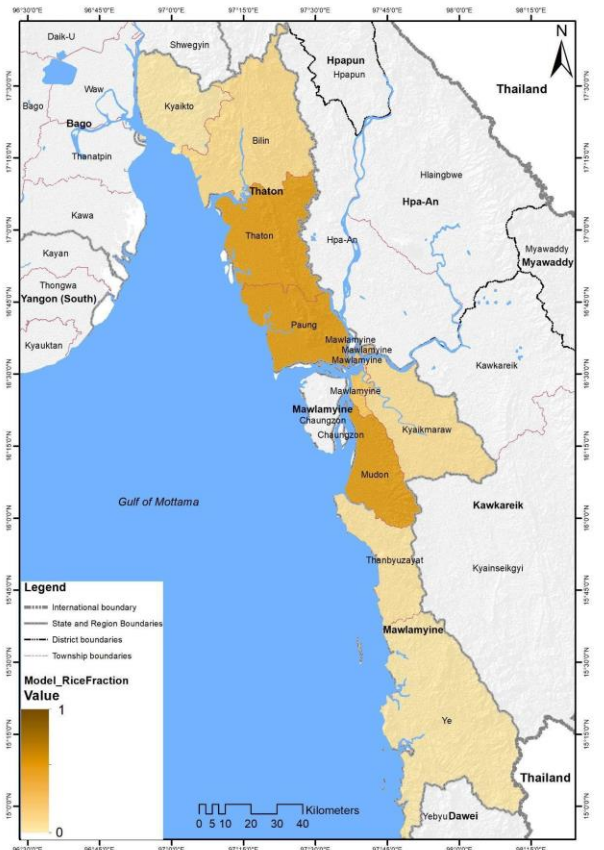
0.35
0.40
0.45

## Mon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Shwegyin
Hpapun
Hpapun
Thailand
Bago
Waw
Kyaikto
Bago
Bilin
Thanatpin
Hlaingbwe
Thaton
Hpa-An
Kawa
Thaton
Hpa-An
Myawaddy
Myawaddy
Kayan
Thongwa
Yangon (South)
Paung
Kyauktan
Mawlamyine
Mawlamyine
Mawlamyine
Kawkareik
Mawlamyine
Mawlamyine
Chaungzon
Chaungzon
Kyaikmaraw
Mudon
Gulf of Mottama
Kawkareik
Thanbyuzayat
Kyainseikgyi
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International boundary
State and Region Boundaries
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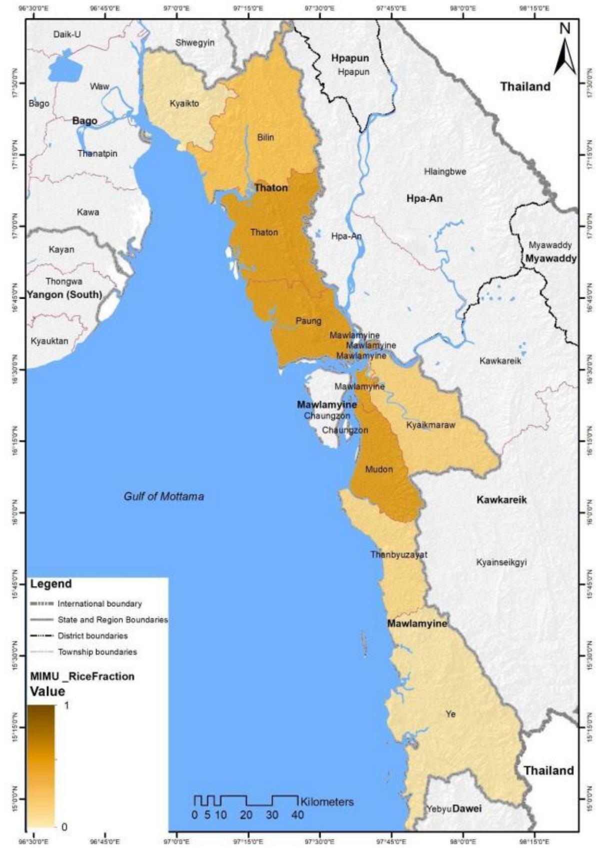
Yebyu Dawei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Shwegyin
Hpapun
Hpapun
Thailand
Waw
Bago
Kyaikto
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Thaton
Hpa-An
Kawa
Thaton
Hpa-An
Myawaddy
Myawaddy
Kayan
Thongwa
Yangon (South)
Paung
Kyauktan
Mawlamyine
Mawlamyine
Mawlamyine
Kawkareik
Mawlamyine
Mawlamyine
Chaungzon
Chaungzon
Kyaikmaraw
Mudon
Gulf of Mottama
Kawkareik
Thanbyuzayat
Kyainseikgyi
Legend
International boundary
State and Region Boundaries
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Township boundaries
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MIMU _RiceFraction
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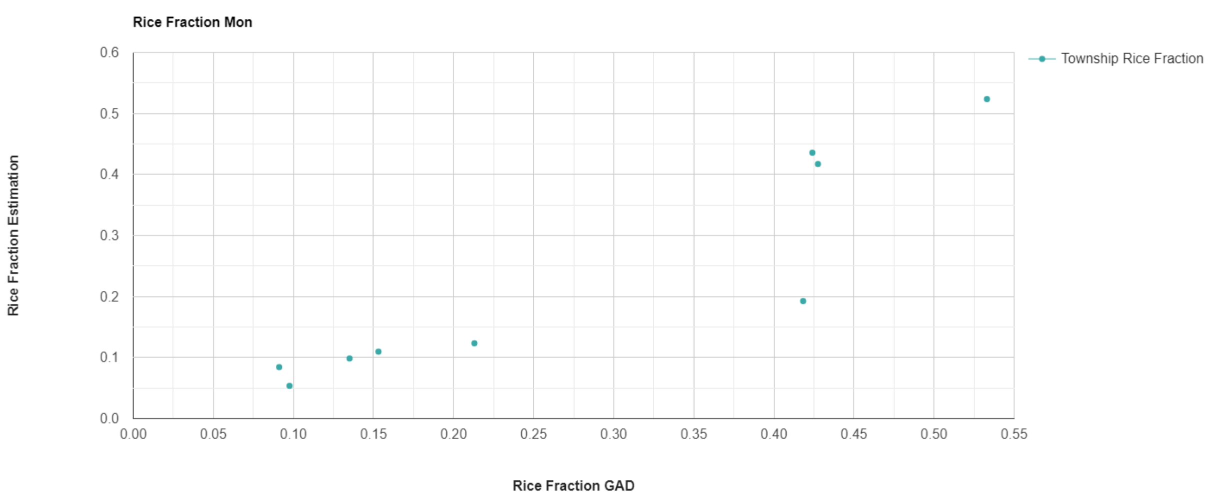
Thailand
0 5 10 20 30 40 Kilometers
Yebyu Dawei


Rice Fraction Mon
Township Rice Fraction
Rice Fraction Estimation
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0.05
0.10
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0.25
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0.35
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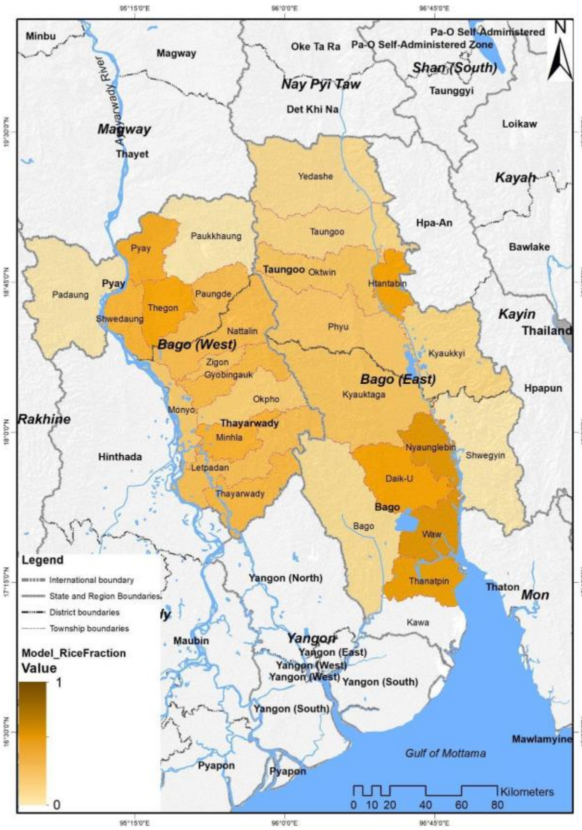
0.45
0.50
0.55
Rice Fraction GAD

Bago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District boundaries
Township boundaries
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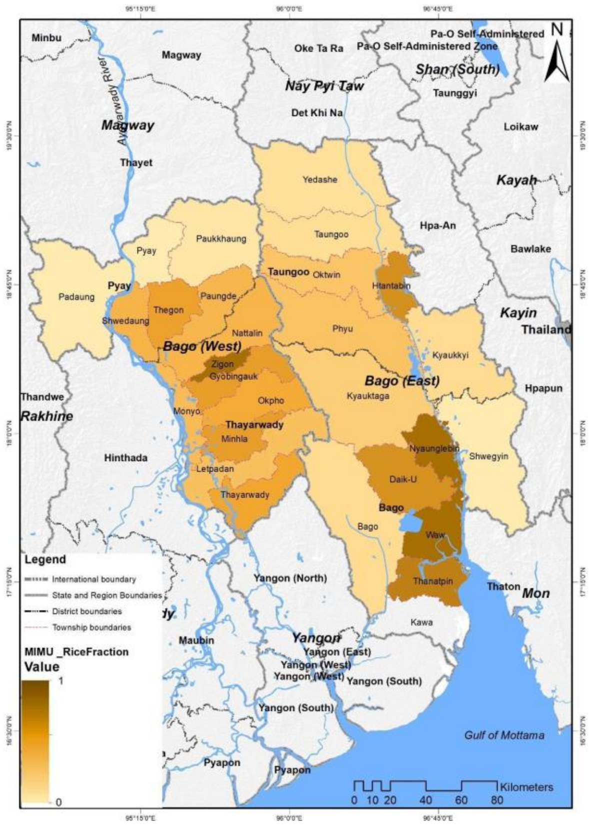
Kilometers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District boundaries
Township boundaries
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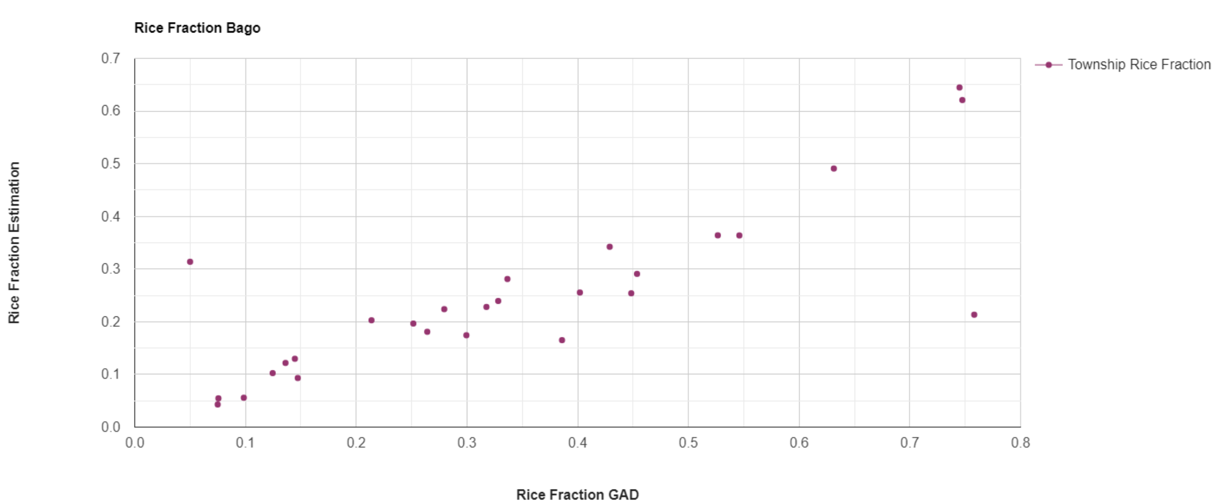
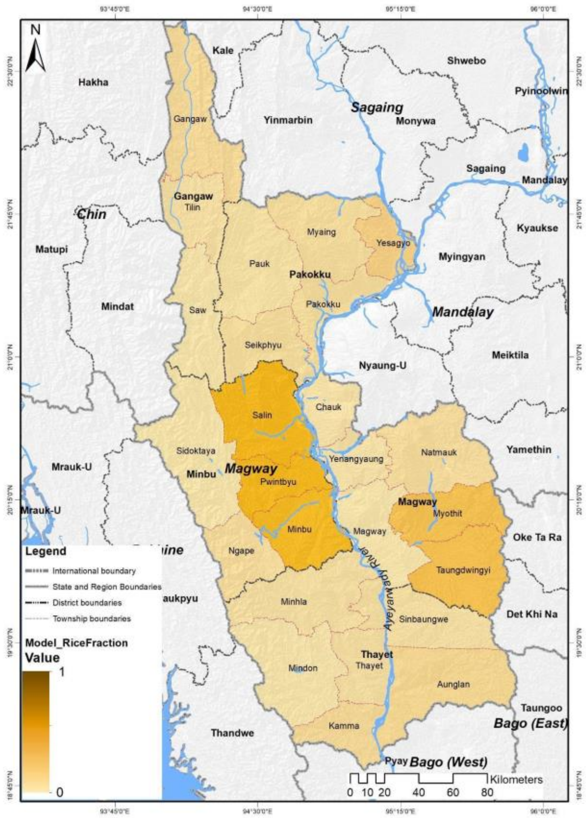
Kilometers


Rice Fraction Bago
Township Rice Fraction
Rice Fraction Estimation
Rice Fraction GAD

Magway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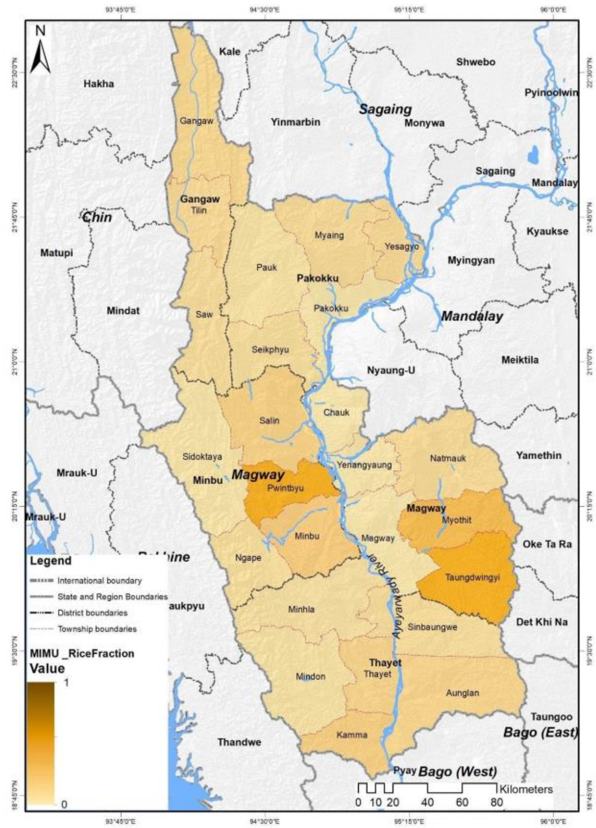
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Kilometers
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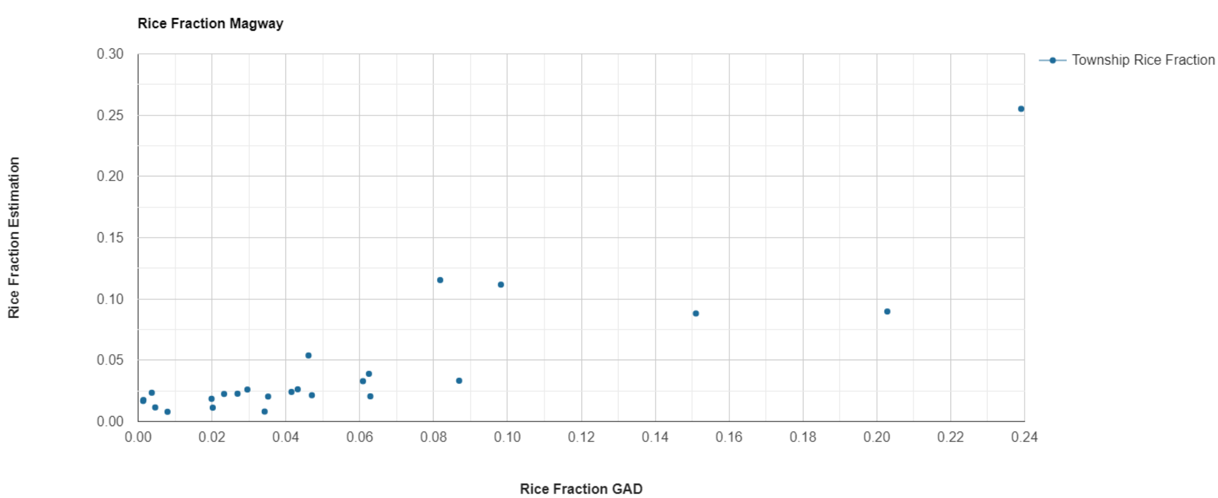
Rice Fraction Magway
Township Rice Fraction
Rice Fraction Estimation
Rice Fraction GAD
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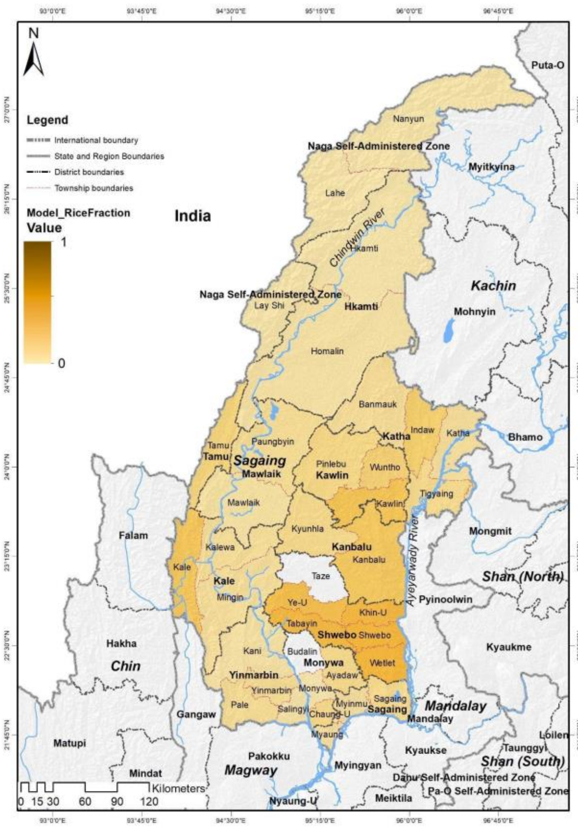
0.25
0.30
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24

## Sagaing



Legend
International boundary
State and Region Boundaries
District boundaries
Township boundaries
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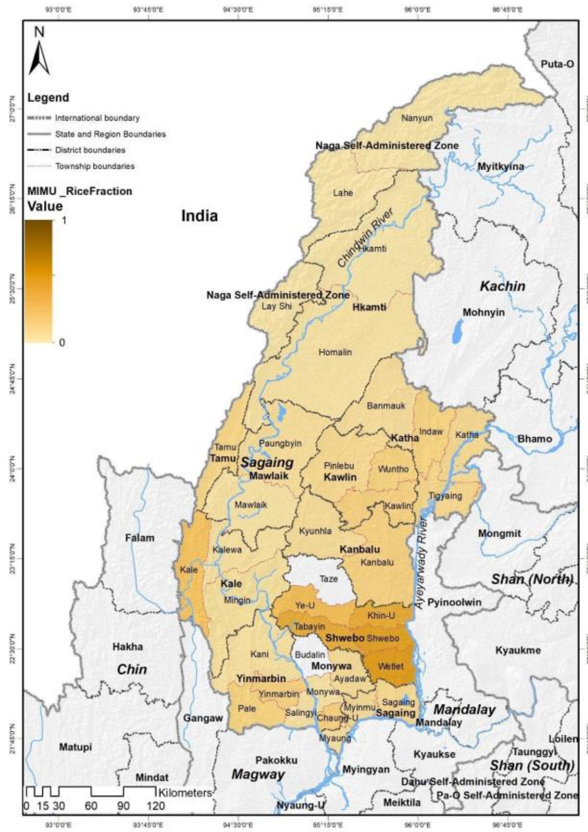
India
Kachin
Sagaing
Chin
Mandalay
Magway
Shan (North)
Shan (South)
Naga Self-Administered Zone
Chindwin River
Ayeyarwady River
Kilometers
0 15 30 60 90 120

Legend
International boundary
State and Region Boundaries
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Township boundaries
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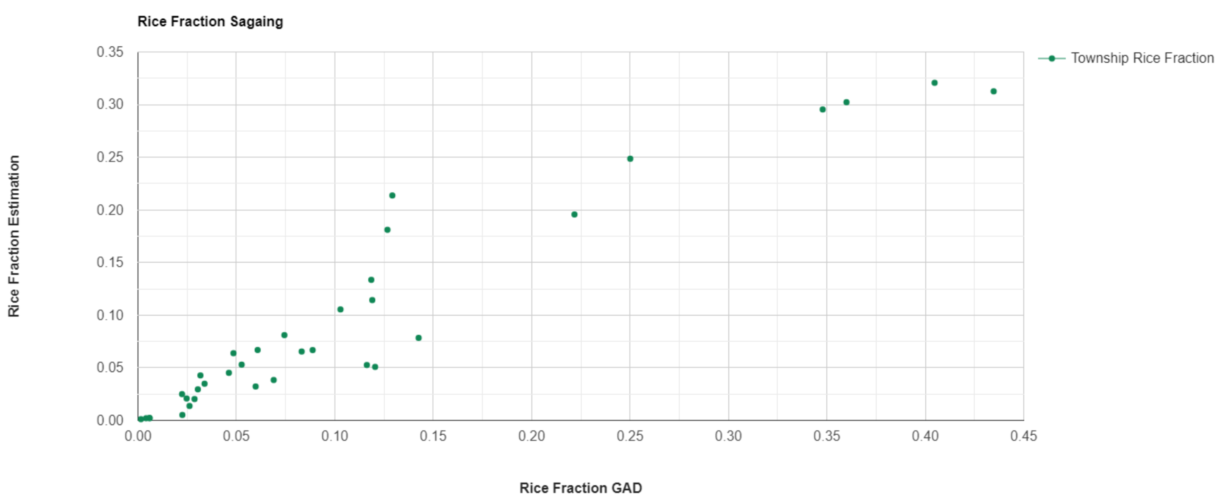
India
Kachin
Sagaing
Chin
Mandalay
Magway
Shan (North)
Shan (South)
Naga Self-Administered Zone
Chindwin River
Ayeyarwady River
Kilometers
0 15 30 60 90 120

Rice Fraction Sagaing
Rice Fraction Estimation
Rice Fraction GAD
Township Rice Fraction
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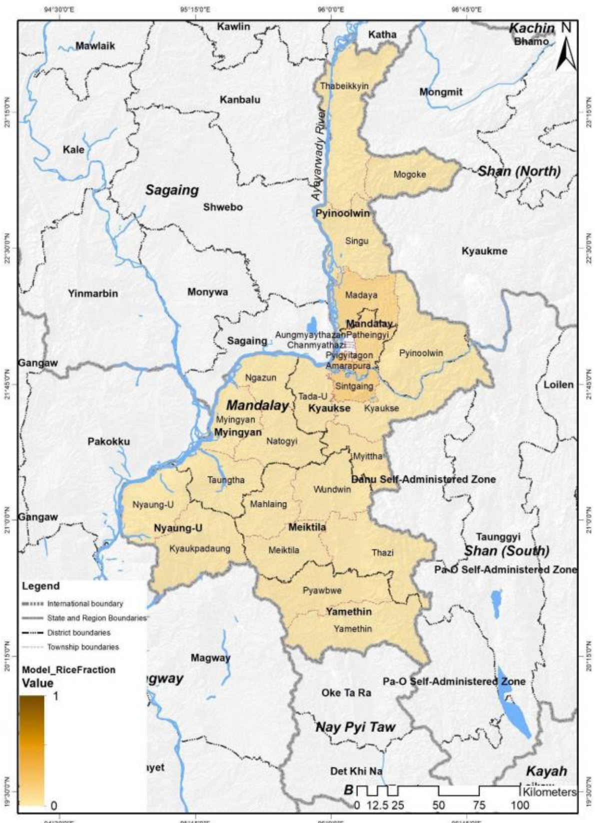
0.25
0.30
0.35
0.40
0.45

Mandalay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District boundaries
Township boundaries
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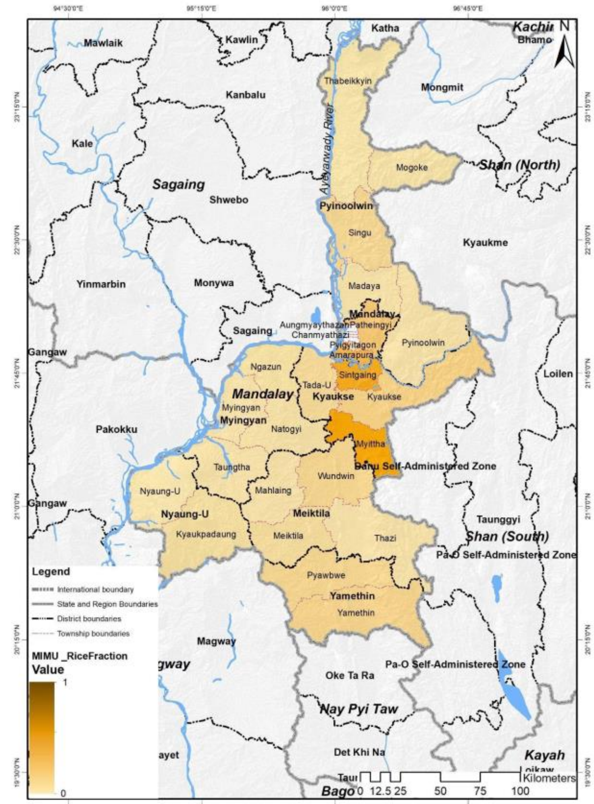
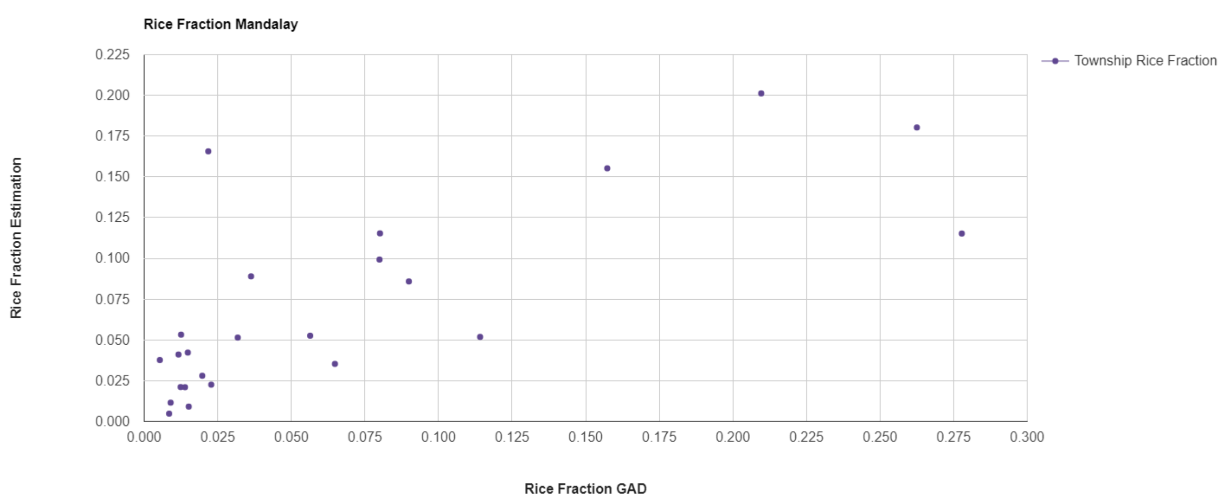
Kachin
Sagaing
Mandalay
Shan (North)
Shan (South)
Magway
Nay Pyi Taw
Kayah
Danu Self-Administered Zone
Pa-O Self-Administered Zone
Ayeyarwady River
Kilometers
0 12.5 25 50 75 100


Legend
International boundary
State and Region Boundaries
District boundaries
Township boundaries
MIMU _RiceFraction
Value
1
0
Kachin
Sagaing
Mandalay
Shan (North)
Shan (South)
Magway
Nay Pyi Taw
Kayah
Bago
Danu Self-Administered Zone
Pa-O Self-Administered Zone
Ayeyarwady River
Kilometers
0 12.5 25 50 75 100


Rice Fraction Mandalay
Township Rice Fraction
Rice Fraction Estimation
Rice Fraction GAD
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.225
0.250
0.275
0.300

## Shan

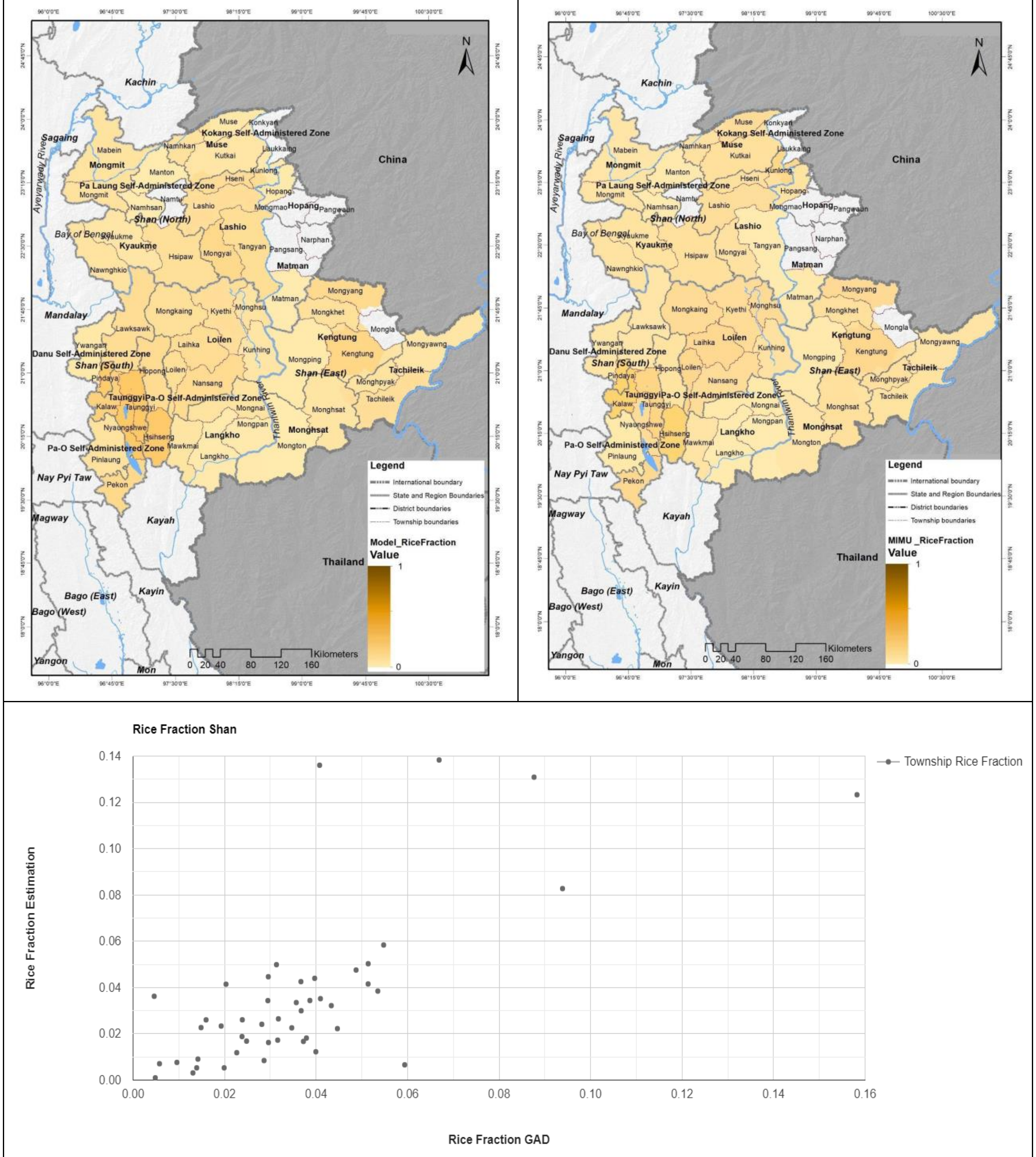



*Figure 13. The percentage of rice area planted relative to total area by township in each State and Region from the ADPC's estimates compared with the rice percentage data from the GAD's Township profile for each State and Region*

### 3.1.3 ADPC Rice Area Estimation Compared to Other Published Values

To assess how our rice map compare to other reports, we have compared the estimates of rice area by state/region with the historical data from the USDA, SCO and GAD reports in Table 10. The total rice cultivation area in the 2021 monsoon season estimated by ADPC for the 9 regions of interest in Burma is 4.8 million (+/- 0.7 million) hectares.

The ADPC total cultivated rice area is lower than the USDA estimates and the CSO Yearbook totals, but in line with the GAD data. We find that ADPC estimates are lower on average cultivated rice area for Yangon, Sagaing and Mon Regions and Rakhine State. We have included rice and deep rice in the analysis for Ayeyawady and Bago, but those specific rice varieties were not explicitly included in the other data sources.

*Table 10. Monsoon rice area in 2021 estimates for 9 States and Regions*

| State and Region | Class Name | USDA* 2020 main crop (ha) | Yearbook 2018 (ha) | GAD 2020 (ha) | ADPC 2021 Estimate (ha) | Uncertainty |
|---|---|---|---|---|---|---|
| Ayeyarwady | Rice | 1,491,363 | 1,499,693 | 1,384,321 | 1,043,045 | 105,781 |
| | Deep-water rice | | | | 353,247 | 64,741 |
| Bago | Rice | 1,089,897 | 1,095,985 | 990,183 | 854,024 | 56,845 |
| | Deep-water rice | | | | 44,246 | 38,401 |
| Yangon | Rice | 468,651 | 471,269 | 372,254 | 362,050 | 21,545 |
| Rakhine | Rice | 414,173 | 416,486 | 396,284 | 364,220 | 28224 |
| Sagaing | Rice | 710,780 | 714,750 | 651,879 | 590,745 | 105,921 |
| Shan | Rice | 513,612 | 516,481 | 239,926 | 512,958 | 147,035 |
| Mandalay | Rice | 222,048 | 223,288 | 163,142 | 198,470 | 44,592 |
| Magway | Rice | 256,604 | 258,037 | 245,578 | 265,059 | 53,180 |
| Mon | Rice | 275,842 | 277,383 | 250,699 | 187,912 | 18,865 |
| **Total** | | **5,442,970** | **5,473,372** | **4,694,266** | **4,775,976** | **685,130** |

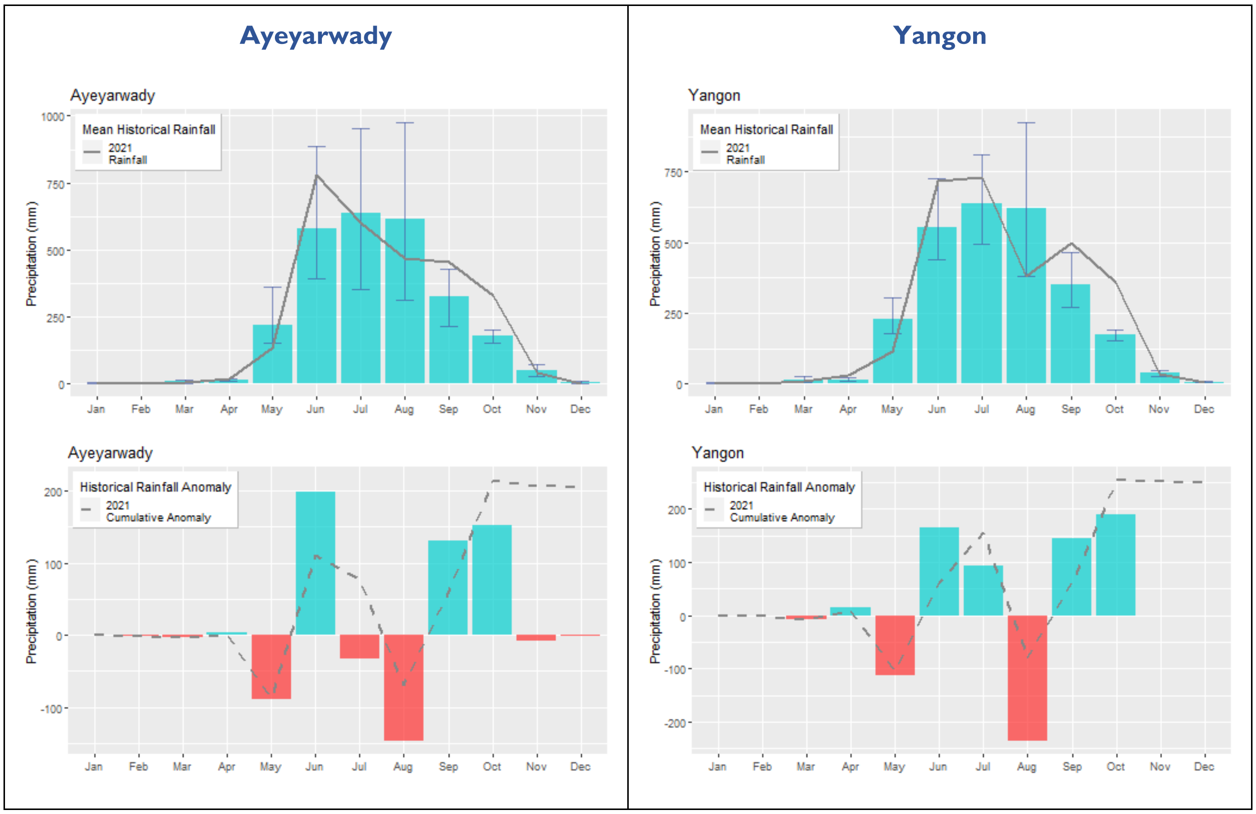
*calculated as a fraction of the total reported.

## 3.2. CLIMATE AND VEGETATION INDEX ANALYSIS

The COVID-19 and political crises have created challenges to the functioning of agricultural value chains and the agri-food system. The COVID-19 pandemic has led to large income declines in the country overall and to substantial disruptions in Burma's agri-food system (Boughton et al. 2021; Headey et al. 2020). The political crisis has caused substantial problems in the banking and finance sector, in international trade, and in the local transport sector, among others (USDA 2021). Increasing rice cultivation costs, such as the cost of fertilizer and seeds, can cause the reduction of yields and production per cultivation unit; and additional analysis about other parameters such as climate and vegetation index can provide information about vegetation health and status of rice growing in the monsoon season in 2021 compared with the trend in the past 10 years. Of key interest is whether the wide array of challenges facing farmers in 2020 and 2021 have altered yields relative to earlier, more stable periods.

## 3.2.1 Climate Data Analysis

Rainfall for the coastal regions is shown in Figure 14. The upper figures show the mean monthly rainfall in 2021 in relation to the historical record (1980-2020). The error bars indicate the 5th and 95th upper and lower limits of the historical rainfall records. The bottom figures show the anomaly and cumulative anomaly. It can be seen that the rainfall for the coastal regions is generally favorable, with an above-average amount of rain for most months. For Yangon and Ayeyarwady, we found below-average rainfall in August, but this was compensated with a higher-than-average amount of rainfall in September. For Rakhine, we found above-average rainfall from June to August, but below-average in the other months.



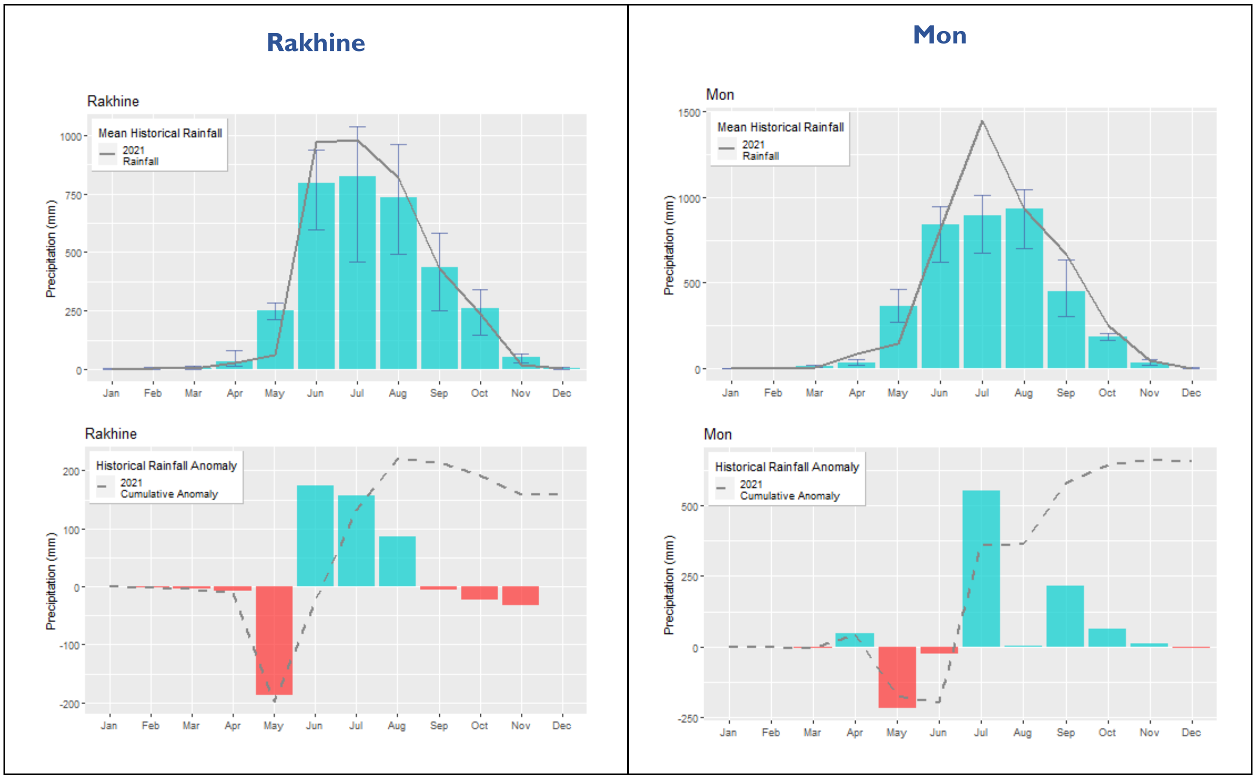



*Figure 14. Rainfall with historical rainfall (top) and rainfall anomaly, cumulative rainfall anomaly (bottom) for the coastal regions.*

In the dryland regions, we found more variability in rainfall in comparison to the lowland floodplain and coastal regions, which can be seen from the length of the error bars for these regions (Figure 15). It was found that there was more rainfall than the historical record, except in Sagaing, which showed a rainfall deficit of 200 mm. For Magway and Mandalay, it was found that the rainfall was below-average at the onset of the planting season in May and June, followed by higher-than-average rainfall in the preceding months.


*Figure 15. Rainfall with historical rainfall (top) and rainfall anomaly, cumulative rainfall anomaly (bottom) for the dryland regions.*

Rainfall in Shan State (Figure 16) was around 100 mm below-average in 2021. Whereas April and May show above-average rainfall amounts, the rainfall amounts from June until September are below-average. However, rainfall amounts are not dramatically low, and October to November months show average rainfall conditions.

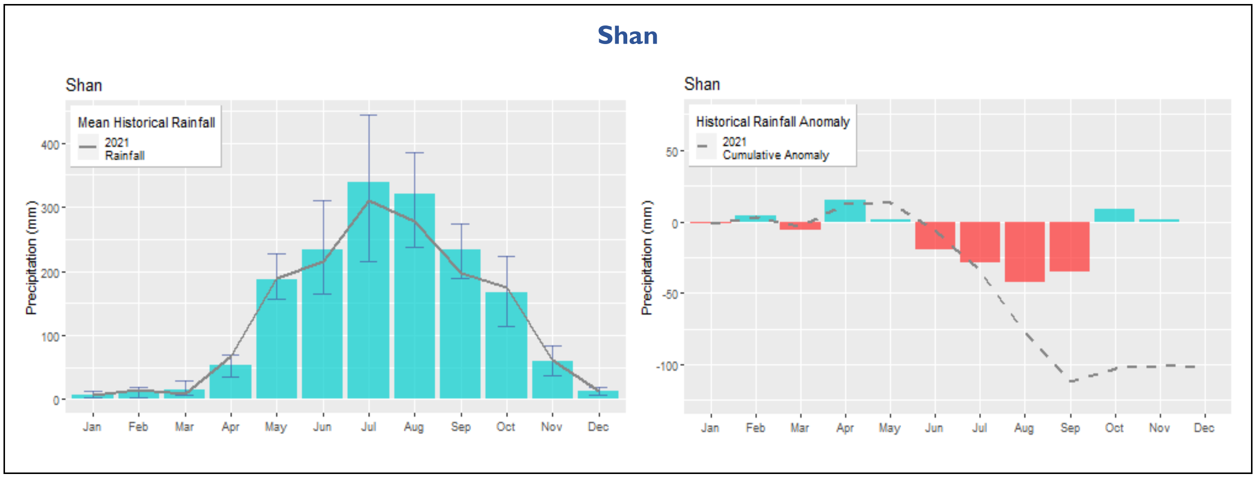



*Figure 16. Rainfall with historical rainfall (top) and rainfall anomaly, cumulative rainfall anomaly (bottom) for Shan State.*

### 3.2.2 Vegetation Index Analysis

The cumulative EVI anomaly analysis compared the vegetation health with the average EVI of the previous ten years. Figure 17 shows the monthly cumulative EVI anomaly per state and region for the year 2021. Positive anomalies indicate a higher EVI compared to the baseline period (2010 - 2020), whereas a negative trend indicates a lower EVI. Higher EVI values are often associated with healthier vegetation. Ayeyarwady, Bago, Yangon, Mon, and Rakhine exhibit positive anomalies throughout the year; Shan's anomalies are negative until April, whereas Mandalay and Sagaing are negative until October after which they show positive anomalies; Magway remains negatively anomalous throughout the year. Note the dip in EVI anomaly observed in June for most states and regions.

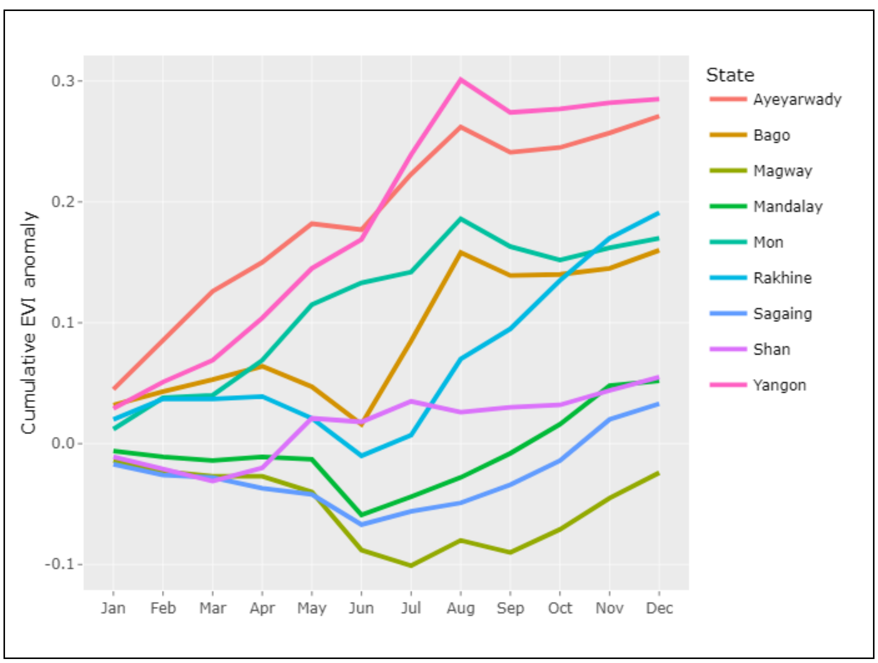
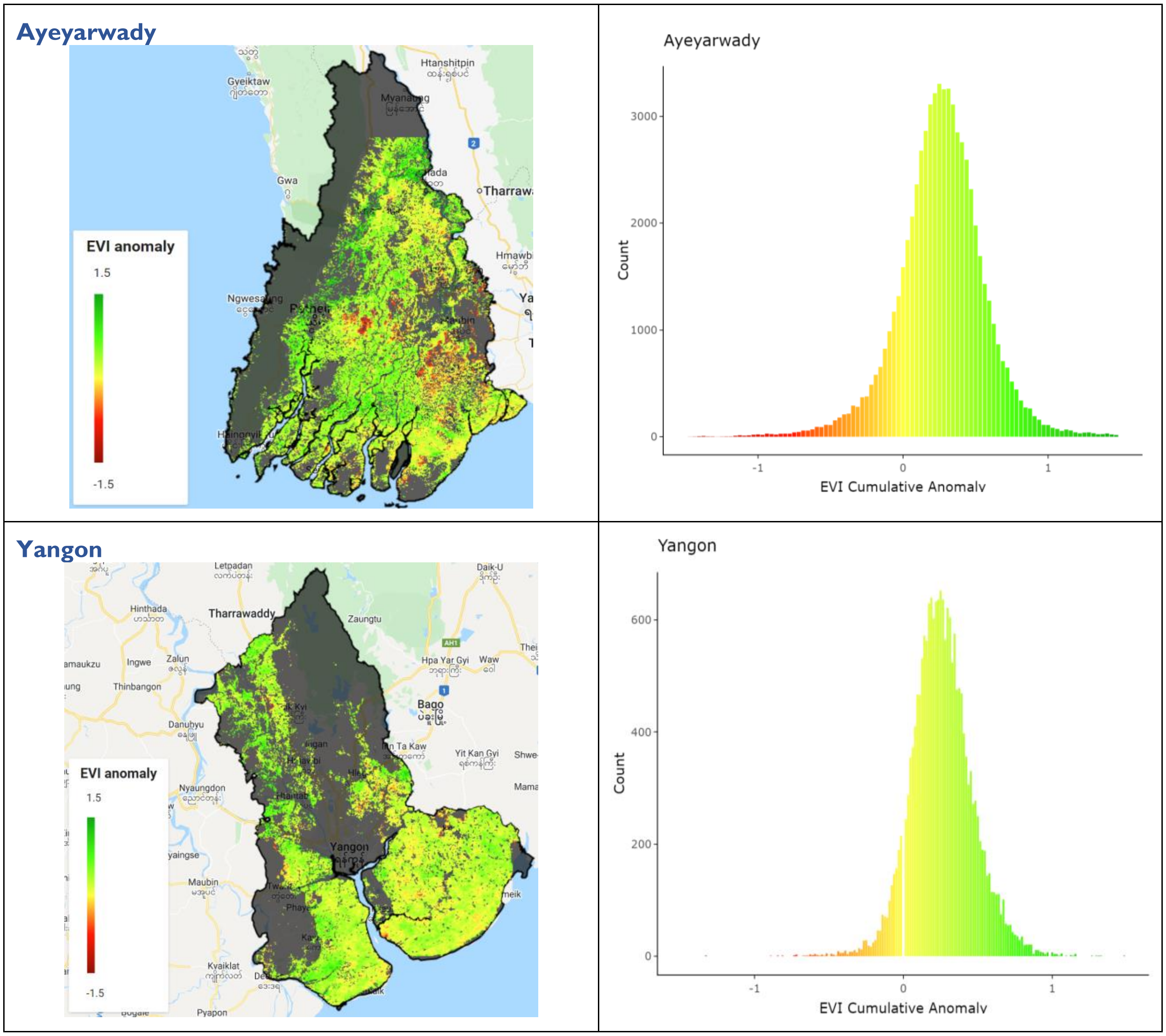



*Figure 17. Monthly cumulative EVI anomaly per state for year 2021.*

The spatial cumulative EVI anomalies for the lowland delta and coastal regions are shown in Figure 18. It can be seen that most regions show positive values, which indicates better vegetation health in 2021. This can also be seen in the anomaly distributions for Ayeyarwady, Yangon and Rakhine, which show positive values for most pixels. For Mon, we found that the conditions are quite similar to the previous ten years with an about-equal amount of positive and negative pixels.



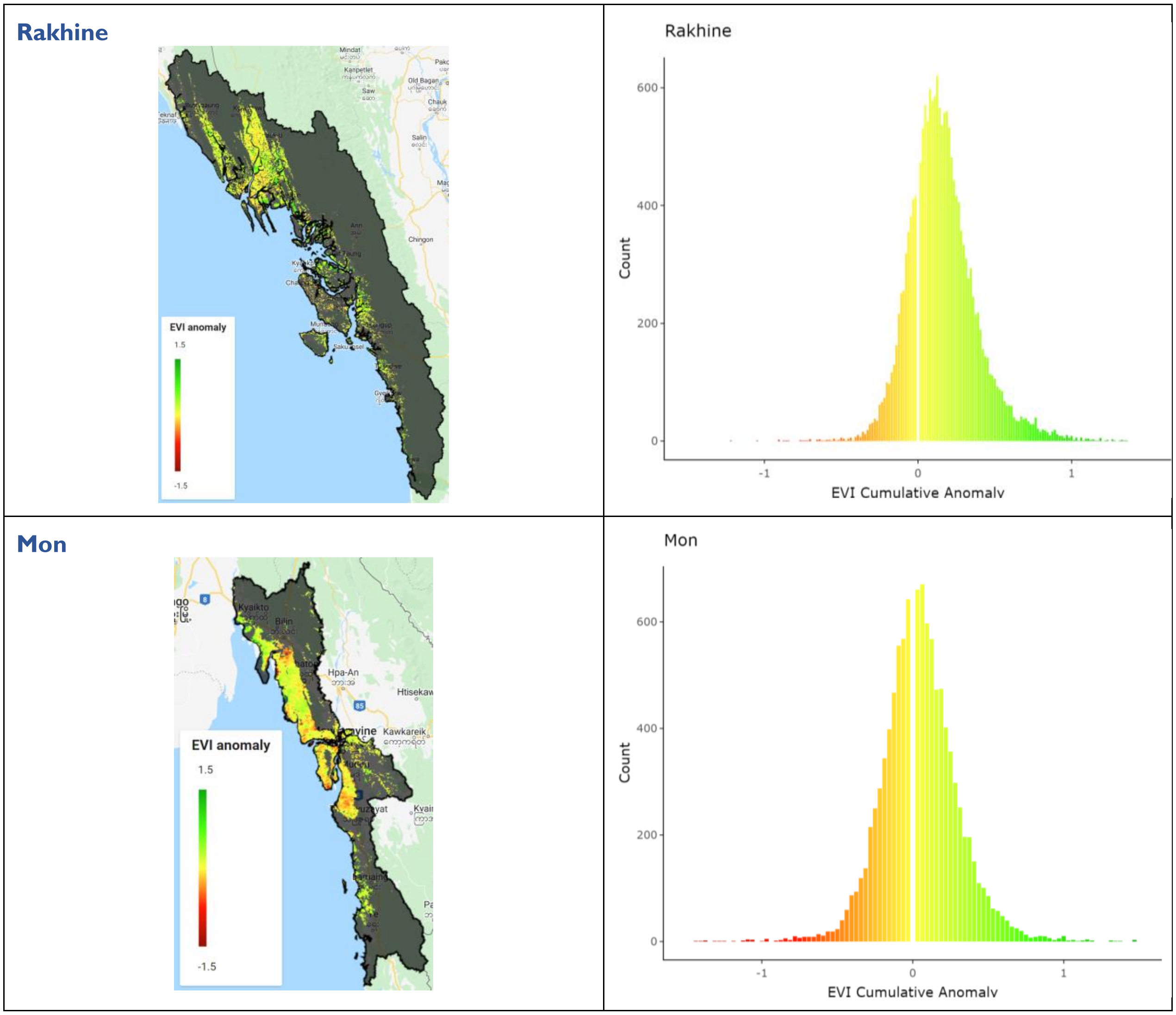
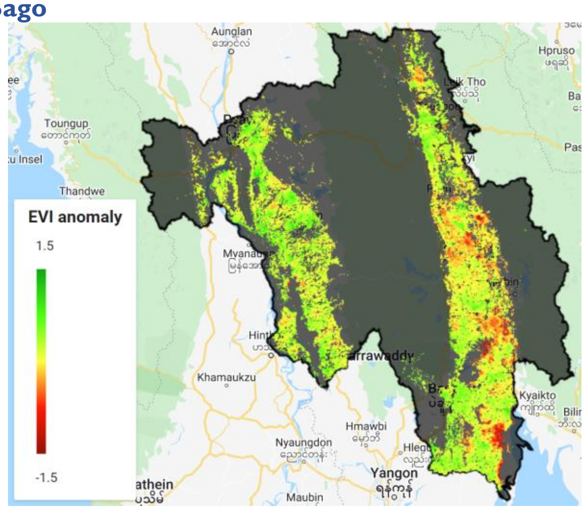
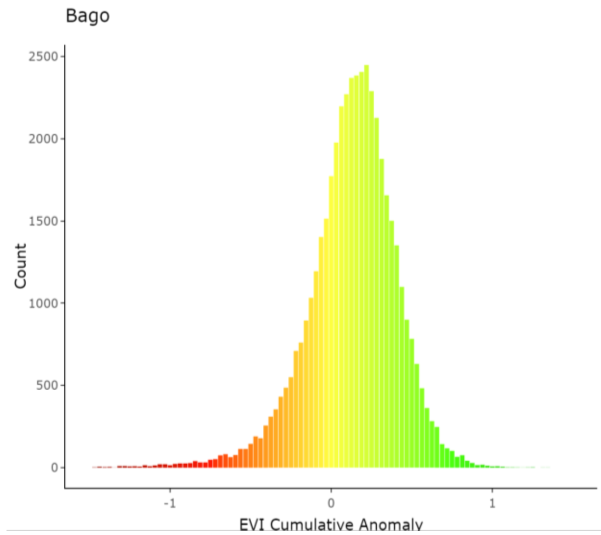
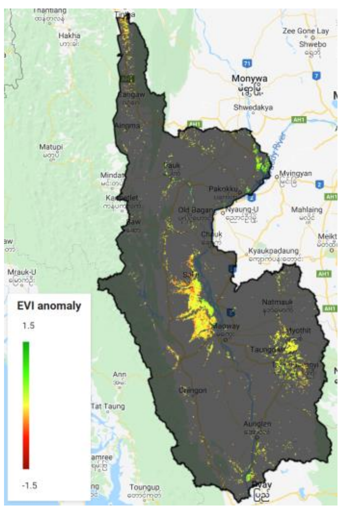
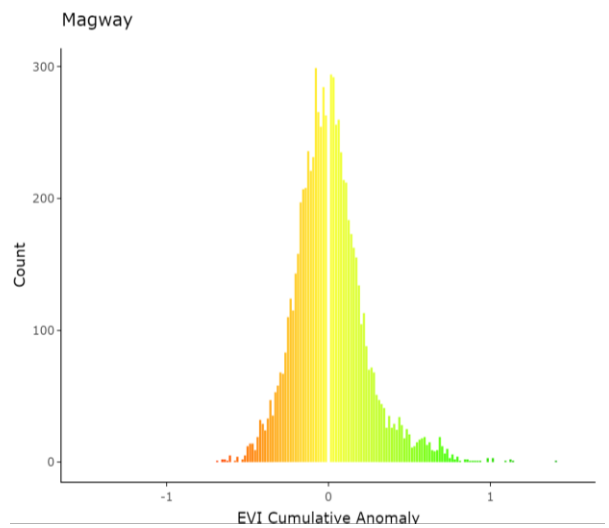
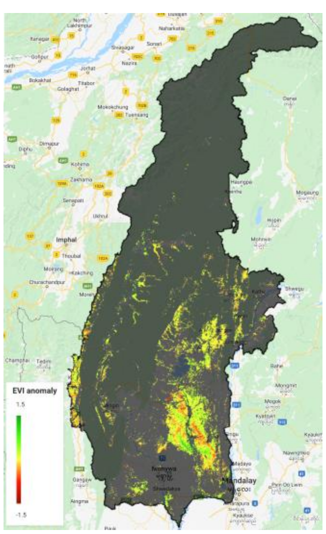
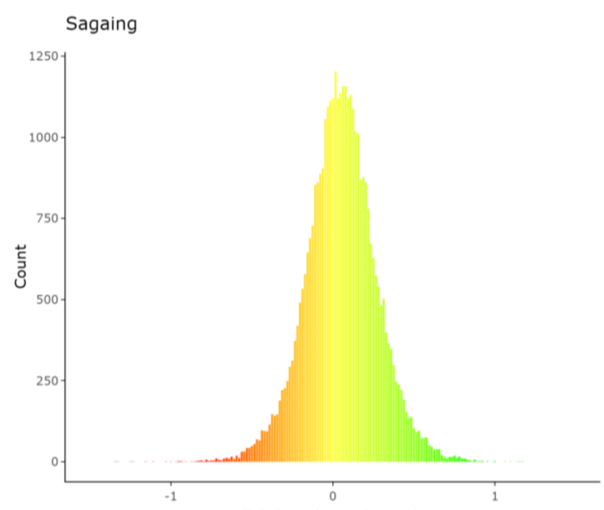



*Figure 18. Cumulative EVI anomaly for states/regions in the delta and coastal zone*

Figure 19 shows the cumulative EVI anomaly for the dryland regions. A similar pattern as the coastal regions can be seen for these regions. On average, the vegetation conditions are better than the baseline. However, some regions, for example Bago, show negative values that require further investigation. The same is seen in Sagaing, where areas with a negative anomaly coincide with conflict areas.

| | |
|---|---|
| **Bago**   |   |
| **Magway**   |   |
| **Sagaing**  |   |

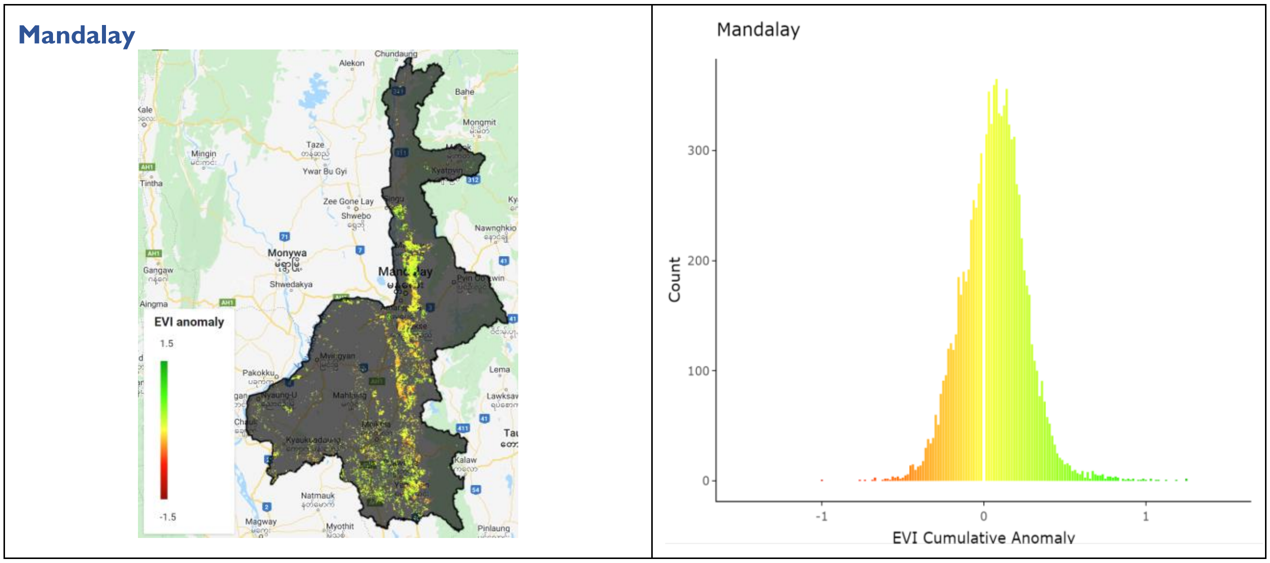


*Figure 19. Cumulative EVI anomaly for dryland regions.*

Shan State shows cumulative EVI values comparable with the baseline. The histogram in Figure 20 shows an equal distribution of positive and negative values across the state. The map shows no clear spatial pattern in negative or positive values.

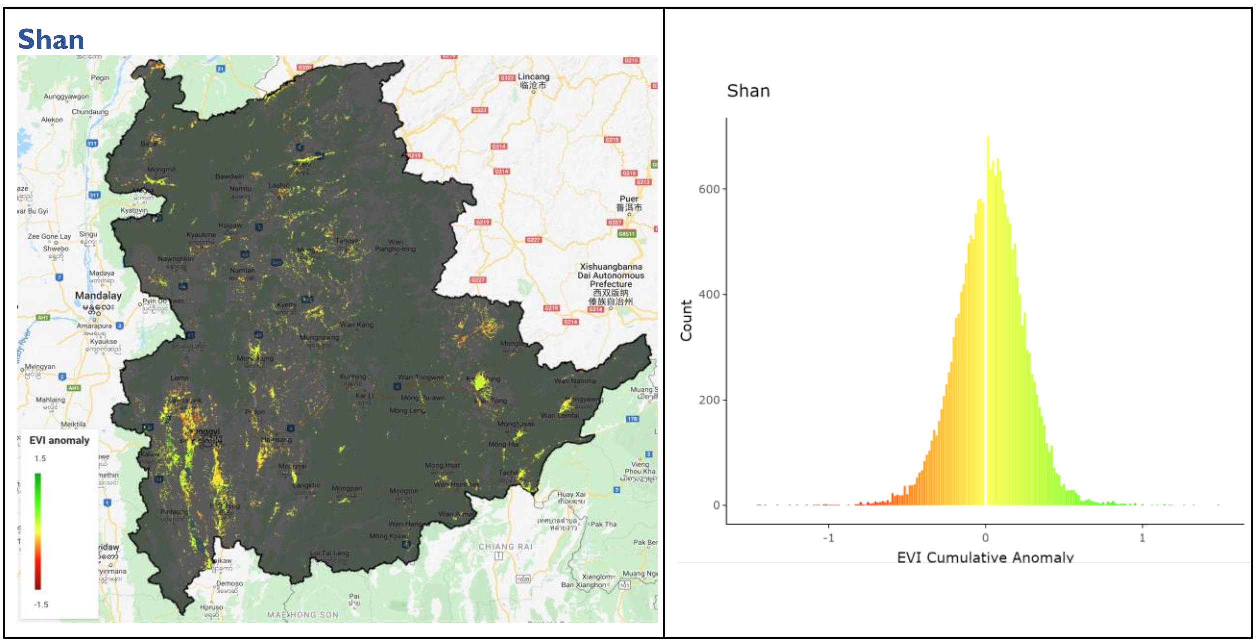


*Figure 20. Cumulative EVI anomaly for Shan regions.*

This additional analysis on the climate parameter and vegetation index shows that rainfall conditions were generally favorable for rice cultivation in Burma during the monsoon season in 2021, and the trend of vegetation health of the rice growing area is not much different in 2021 than in the past 10 years. This analysis proves that climate conditions do not impact the rice yield in 2021, which allows us to use the rice yield estimation by MAPS method from IFPRI, which could reflect the impact of current political issues and economic situation in Burma.

## 3.3. ESTIMATES OF RICE YIELD AND PRODUCTION

The historical yield, and production of monsoon rice season estimates from different sources were combined with our estimated area and production. The estimated results and comparison with crop yield and production are shown in Table 11. It can be seen that for GAD there is a wide range in minimum and maximum reported yield, where the lower values do not seem in line with other data sources. The reported yields in the Yearbook are higher than the numbers used by the USDA, which results in higher production estimates. We also use the yield estimates by the IFPRI study, multiplied with our area estimates to estimate total production. It can be seen that the total rice production estimate is lower than the numbers reported by the yearbook and USDA, but higher than GAD. Notably, there is a discrepancy between Sagaing, where a total rice production of 3,023 thousand tons was reported by the yearbook, whereas GAD reports 798. Our estimates for Sagain show a total production of 2052 thousand tons, in line with the USDA estimates. Whereas our area estimates show a decrease in comparison with the ones estimated for the USDA data, our production estimates are more in line with the historical reported values due to on average higher yield estimates.

*Table 11. Yield and production of monsoon rice season in 2021 estimates per state and region.*

| State and Region | Class Name | USDA* (2020) | Yearbook (2018) | | GAD (2020) | | IFPRI (2021) | ADPC Estimate 2021 | | Uncertainty |
|---|---|---|---|---|---|---|---|---|---|---|
| | | prod | yield | prod | yield | prod | yield | Area | (prod)** | |
| Ayeyarwady | Rice | 4176 | 3.92 | | 3.57 | | 2.82 | 1,043,045 | 2943 | 299 |
| | D. rice | | | 5879 | | 4937 | 1.57 | 353,247 | 553 | 101 |
| Bago | Rice | 3052 | 3.83 | | 2.69 | | 3.32 | 854,024 | 2834 | 189 |
| | D. rice | | | 4198 | | 2659 | 1.57 | 44,246 | 69 | 60 |
| Yangon | Rice | 1312 | 3.54 | 1668 | 2.79 | 1039 | 2.9 | 362,050 | 1049 | 62 |
| Rakhine | Rice | 1160 | 3.13 | 1304 | 2.43 | 962 | 3.15 | 364,220 | 1148 | 89 |
| Sagaing | Rice | 1990 | 4.23 | 3023 | 1.22 | 798 | 3.47 | 590,745 | 2052 | 368 |
| Shan | Rice | 1438 | 3.86 | 1994 | 3.02 | 725 | 2.88 | 512,958 | 1477 | 423 |
| Mandalay | Rice | 622 | 4.26 | 951 | 0.4 | 65 | 3.58 | 198,470 | 711 | 160 |
| Magway | Rice | 718 | 3.87 | 999 | 1.6 | 394 | 3.71 | 265,059 | 984 | 198 |
| Mon | Rice | 772 | 3.27 | 907 | 1.77 | 444 | 2.99 | 187,912 | 563 | 56 |
| | **Total** | **15,240** | | **20,922** | | **12,023** | | **4,775,976** | **14,383** | **2,005** |

*calculated as a fraction of the total reported.

** estimate was calculated by multiplying area with the IRPRI yield of each state/region

STAR News reported that on April 7th, 2022 the Burma Rice Federation (MRF) reported that Burma exported over 1.4 million metric tons of rice and broken rice in the six-month interim budget period (The Star News, 2022; October 2021 to March 2022). This number shows a slight reduction of rice exports by Burma compared to recent years. The country exported some 1.87 million metric tons of rice and broken rice in the 2020-2021 fiscal year and 2.5 million metric tons in 2019-2020 fiscal year (these fiscal years cover 12 months). The country is now exporting rice and broken rice via sea routes as its border export has been disrupted by the Covid-19 pandemic.

# 4. DISCUSSION

This report presented the results for rice area and production estimates for nine regions in Burma. The results show that the cultivated area in most states is quite similar to the historically reported ones, using our best estimates. This approach presents our best first estimates for the monsoon season which were compared with historical data from various sources. However, historical data are ambiguous and they present a wide range of area, yield and production estimates. As such, it remains difficult to quantify the potential impacts of COVID and political unrest Moreover, for states with a smaller portion of rice the width of the confidence intervals on area estimates, yield, and productions should be improved in order to achieve more accurate and reliable results. Below we list several factors that could help improve the accuracy of our estimates.

- The reported historical rice area and rice yield from different sources reflect different time periods and aggregate at different geographic scales. USDA data provide estimates at the country level, on a yearly basis and data is recently updated in 2020-2021; the Statistical Yearbook reports data at the region/state level and on a yearly basis but latest available data was in 2018; the GAD data provide information at the township level for each season with updated in 2020, therefore, some data are more current than others. The total numbers and aggregated totals vary. There is reasonable agreement between the different sources in terms of area estimates, but a rather large gap in terms of yield and thus production estimates. A discussion on the reliability of this data and additional information could be useful in refining these estimates.

- The coastal regions have much smaller confidence intervals for the area estimates than the other states. Other states have different climates that also result in a different phenological signal of rice, making them more similar to other crops. Moreover, there seems to be more variation in the crop choice in those regions. As such, the machine learning models have more issues in distinguishing between rice and other crops in those regions. In this study, a large amount of additional data was added to improve the results. Adding more reference data while looking for distinct signals in the satellite imagery could help mitigate this issue.

- The GAD data is a rich source as it provides data for each season for every township. These data were downloaded and digitized and have not been used to its full potential in the data analysis. Our results show a general good agreement between GAD township data on rice area with our ADPC estimates. This will be investigated further.

- Rice yield estimates at the state and regional level from IFPRI were used to calculate total rice production for each state and region. These were deemed most reliable as the values were estimated based on a 2021 monsoon survey. They would incorporate the impact of increasing prices of inputs and access to capital that could have affected rice yields in a negative manner.

- Whereas the vegetation health imagery looks generally favorable compared to the historical record, some rice-growing areas indicate a steep decline. Some of the areas were linked to civil unrest, while more investigation is required to identify the potential drivers there.

- Our 2021 national monsoon rice crop production estimates are in line with the 2020 and 2021 USDA rice crop production estimates. The data on climate and area estimates and vegetation indices do not show evidence for a sharp decline in production compared to the reported 2020 main crop numbers.

- Conflict and civil unrest can be an important driver in the reduction of agricultural outputs in specific areas. Figure 22 shows the incident map of conflicts over the country, which were also digitized and overlaid with our rice and vegetation data. However, more investigation is needed to find a plausible correlation on the potential impacts of conflict on agricultural production.

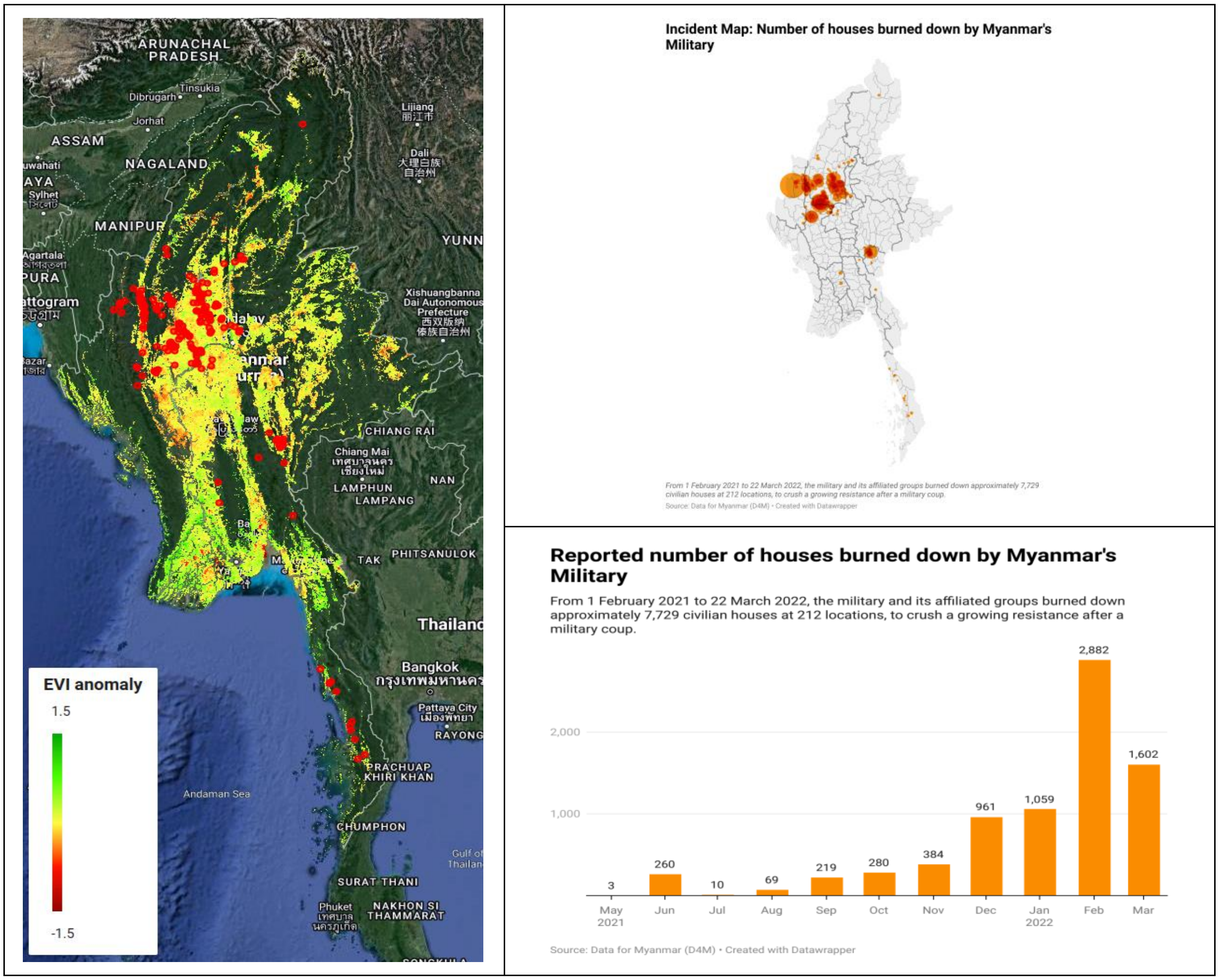



*Figure 21. Conflict areas in Burma in 2021. The left image shows the conflict areas overlaid with vegetation index.*

# 5. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

In this report rice production for the 9 states with highest rice production in Burma were assessed for the monsoon 2021 season. Rice production is critical for those states and Burma as a whole as the pandemic, political instability and surging inflation threaten the country's food security situation.

Based on our assessment we can draw the following conclusions:

- Rainfall conditions were favorable over the growing season, except in the Sagaing Region and Shan State that received below-average rainfall.
- The cumulative EVI anomaly showed average increasing trends over the rice-growing season.
- Total area estimates were lower than the historical ones reported by USDA and the Statistical Yearbook, but higher than the ones reported by GAD.
- We estimate a total area of 4.8 million (+/- 0.7 million) hectares of rice planted for the 2021 monsoon rice season. This number is lower than the 5.4 million hectares reported by the USDA and the CSO Statistical Yearbook, but higher than the 4.7 million ha reported by GAD.
- We estimate that a total of 14,383 thousand metric tons (+/- 2005) of rice were produced in the 2021 monsoon season. This number is slightly lower than the numbers reported by USDA in 2020 (15,240 thousand ton) and the CSO Statistical Yearbook in 2018 (20,922 thousand ton), but higher than the GAD in 2020 (12,023 thousand tons).
- There is no clear evidence that a sharp reduction in rice production occurred during the 2021 monsoon season from image interpretation, except for in the Sagaing Region. Sagaing had lower area estimates than historically reported, which coincided with negative EVI trends and conflict areas. In Sagaing, we note an increase in the intensity of conflict incidents over this period, which may extend to production declines of post-monsoon, "summer" rice.
- Looking forward, ADPC will conduct a similar satellite-based rice crop estimate for the post-monsoon, "summer" rice crop. Media reports note many continuing challenges for farmers during this period.

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