Project Report – Analysis of Remote Sensing Imagery, Harvard University, December 2019
Identifying Opium Poppy in Afghanistan (without High Resolution Images)

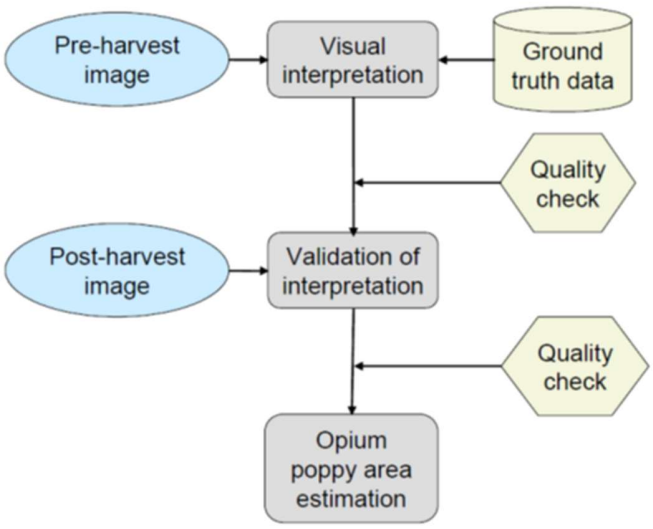
I. Background Information and Motivation

Afghanistan is currently the country with the largest areas under opium poppy cultivation worldwide (82 percent of total global area) (UNODC, 2019a). Opium poppy cultivation is widespread and takes place in 24 of the 34 provinces of this country (UNODC, 2019b). In this regard, opiates have become a crucial pillar of Afghanistan's economy and rural communities had become dependent on the income from opium poppy to sustain their precarious livelihoods (UNODC, 2019c). At the same time, opiates provide income to anti-government and terrorist groups, mainly through forced "taxation" to farmers, which fuels violence, exacerbates the on-going war, and impedes development in this country. As such, opium poppy cultivation is at present one of the most important axes that sustain the vicious circle of violence and underdevelopment in Afghanistan. Providing sustainable solutions to this complex problem requires the availability of reliable evidence about which specific (income and non-income) poverty and security-related factors play a significant role in illicit crop cultivation. Those factors have proved to be very different based on the geographic location of the affected communities and ideally should be identified per community to be able to deliver effective and targeted development-related responses that address their most relevant and urgent needs.

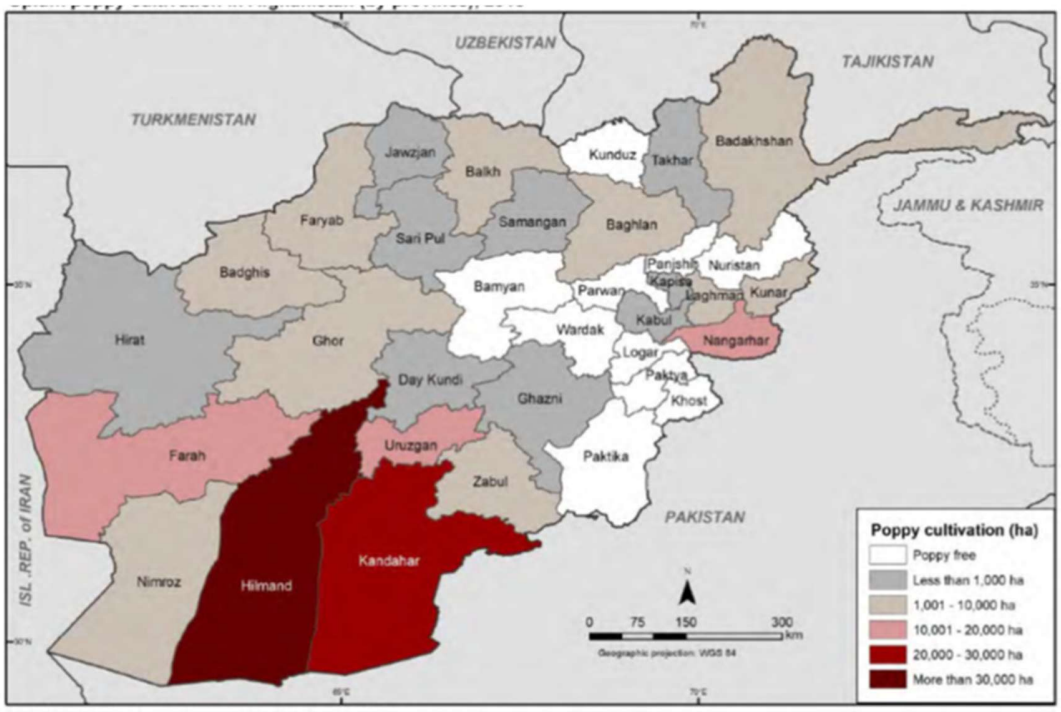
To inform about the extent of opium poppy areas in Afghanistan, the United Nations Office on Drugs and Crime (UNODC) conducts annual monitoring surveys using remote sensing images since 2002. However, the estimation methods have changed over time and since 2015, UNODC is using a combination of approaches based on the historical extend of opium poppy areas per province. In provinces with large opium poppy cultivation, UNODC applies a sampling approach; in provinces with low levels of opium poppy growing, UNODC uses a targeted approach using full coverage of satellite imagery for the affected portions of those provinces. In provinces without previous indication of poppy cultivation, UNODC employs a village survey approach (*i.e.,* interviews with village headmen and farmers on the status and changes on opium poppy cultivation). In 2018, out of the 34 provinces, 17 were sampled, 11 were targeted, and 6 were considered poppy-free (with fewer than 100 opium poppy hectares) (UNODC, 2019b).

For the estimation, UNODC relies on remote sensing images which are obtained to temporally align the flowering phase and the post-harvest phase of opium poppy, as this crop is usually plowed immediately after harvest whereas other crops with similar spectral signatures as wheat are commonly not. UNODC visually delineates opium poppy plots from 0.5-meter resolution PLEIADES images, and combines this information with ground-truth data and field photos tagged with latitude and longitude coordinates.

Finally, UNODC utilizes a statistical relationship based on the ratio of opium poppy to potential agricultural land to estimate the total opium poppy areas per province, as shown in Map 1 (below). However, the location of all opium poppy plots is currently unavailable for the sampling provinces (which are actually the provinces with the largest opium poppy cultivation), although this kind of information is essential to generate other geo-referenced and targeted products for evidence-based decision making. Therefore, this project aims to contribute to identify alternatives for locating the missing opium poppy plots, based on open source medium resolution remote sensing data (Landsat 8).



Graph 1: Flow diagram for identification or opium poppy by UNODC. Source: UNODC (2019b)



Map 1: Total Opium Poppy Areas per Province in Afghanistan, 2018. Source: UNODC (2019b)

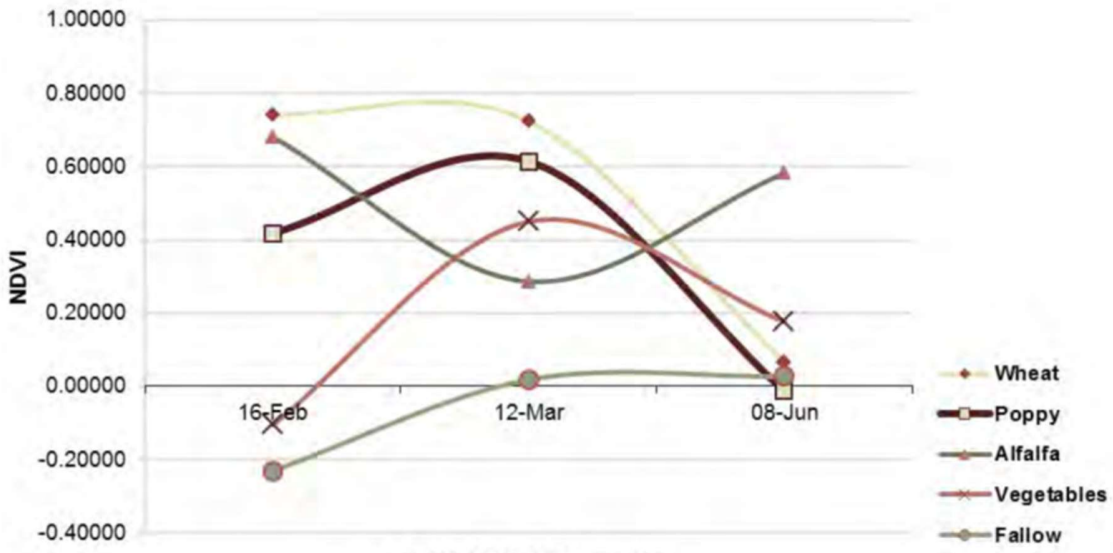
General problems with opium poppy identification

The identification of opium poppy plots is not without problems. In general, the NDVI values of opium poppy in a given time are very similar to the NDVI values of other crops, in particular wheat, which cultivation is also a widespread in Afghanistan. However, during flowering the NDVI values of opium poppy are lower than the NDVI of most of the other crops. Then after harvesting, opium

poppy plots are ploughed, which sharply decrease their NDVI values. This pattern of change in NDVI values has been used to detect opium poppy by UNODC and other authors (Simms, 2016, USAID, 2019).

Unfortunately, opium poppy calendars are not available, so we do not know for sure in which months flowering and harvest occur per specific location. In addition, the NDVI values during the opium poppy cycle vary strongly with altitude, irrigation, and other climatic conditions (such as dry or rainy years) (Yichen *et. al*, 2011). Simms (2016) also indicated that there is wide variation in NDVI values due to differences in latitude and elevation that control the timing of opium poppy cycles, including a two-month difference in first-peak NDVI between adjacent valleys in Badakhshan Province, due to differences in elevation.

Other authors have tried to use medium resolution images to identify opium poppy plots and got estimates with errors larger than 25 percent when compared with the results obtained using high or very high-resolution images (Simms, 2016, USAID, 2019).



Graph 2: Example of NDVI crop values during opium poppy flowering (February) and post-harvesting (June). Source: UNODC (2019b)

Additional problems when using low resolution images:
There are also additional problems with the identification of opium poppy from medium resolution images. For example, opium poppy plots in Afghanistan tend to be very small with several of no more than 200 m^2, which are actually smaller than one Landsat pixel, which size is of 900 m^2. There is also intercropping of poppy fields with other crops, although it is not very common.

So the very small size of opium poppy plots and intercropping generate "mixed pixels". The NDVI values of those pixels correspond to not only opium poppy but to a combination of crops, which makes more difficult the detection of opium poppy.

II. Research Question

How to identify opium poppy cultivation in Afghanistan (without high-resolution images)?

III. Methodology and Remote Sensing Processing Steps

For this project, only Achin district in Nangahar province was covered due to time constraint (located in Southern Afghanistan). This district was chosen because it was not affected by drought in 2018 and was a location of "alternative development" projects and it is a place of interest by international donors. The method followed was based on the NDVI values during the opium poppy growth, and its steps are indicated below:

a) Select and download remote sensing images

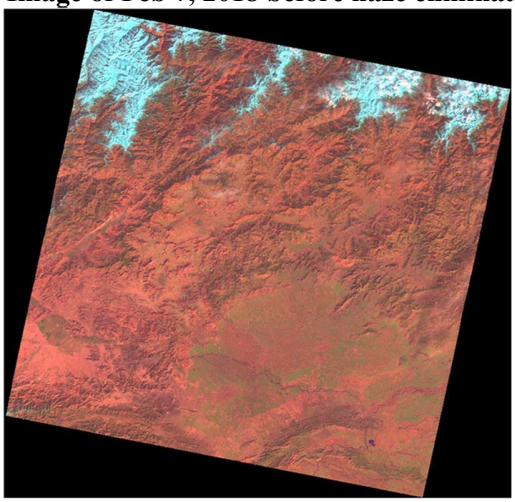
A search of remote sensing images was conducted in Earth Explorer (https://earthexplorer.usgs.gov/) for Achin district in Afghanistan (which corresponded to Path 151, Row 36), using the Landsat Collection 1 Level-1 (Landsat 8 OLI/TIRS C1 Level-1) with the additional criteria of less than 10 percent of land cloud cover. The available images corresponded to the following dates:

-January 6, 2018
-January 22, 2018
-February 7, 2018
-April 12, 2018
-April 28, 2018
-May 30, 2018
-July 1, 2018
-September 19, 2018
-October 21, 2018
-November 6, 2018

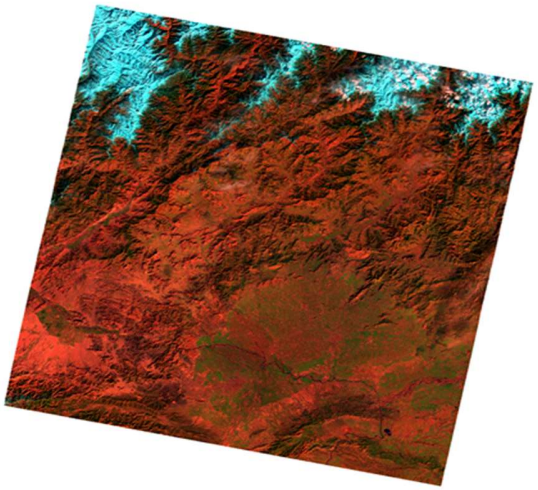
b) Pre-processing

After downloading all the images, the bands were stacked together per image, haze was eliminated from each of the images using the Dark Object Subtraction 1 (DOS 1) method, and then were clipped to the extent of Achin district political boundaries.

Image of Feb 7, 2018 before haze elimination



Same image after haze elimination



c) Processing

Then the images were processed by calculating their NDVI values using the following formula:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

d) Classification

Afterwards, each of the images was classified based on the following NDVI ranges:

<0	Water or snow
0-0.2	(Bare) soil or similar
0.2-0.4	Vegetation with low to moderate growth
>0.4	Vegetation with intense growth

e) Re-classification

There were months without image coverage, such as August, which seemed to be the month in which flowering happened. Alternatively, images from April and July during which opium poppy was likely in intense growth, and an image of November during which the soil should have been already ploughed and was probably showing initial natural regrowth were selected to reflect opium poppy growth. As such, a final map was created in which the pixels with NDVI values larger than 0.4 in April 12 and July 1, and between 0.2 and 0.4 in November 6 were classified as opium poppy.[1]

f) Checking results:

Twenty points were randomly selected inside the polygons classified as opium poppy in the final image, and the changes in NDVI values over the whole year 2018 for those points were analysed using AppEEARS (1_km_monthly_NDVI, MOD13A3.006). In addition, a DEM layer was also included in AppEEARS to evaluate if the results differed based on altitude (Band1, SRTMGL1.003).

g) Validation of results:

The results were validated by adding up the area of all polygons classified as poppy in the final map and comparing it with the total poppy area officially reported by UNODC for Achin district in 2018.

IV. Description of Remote Sensing Data

Landsat 8 OLI multispectral (11-band) imagery covering the full extent of the Achin district was downloaded using the USGS Earth Explorer portal (https://earthexplorer.usgs.gov/). The imagery was available for the full archive of Landsat 8 OLI scenes and has been radiometrically calibrated, orthorectified, and projected into the Universal Transverse Mercator (UTM) coordinate system (processing level L1TP) and was therefore suitable for analytic purposes. The query also included that the amount of land cloud cover was less than 10 percent. The list of selected images is provided in section IIIa above.

Ancillary data:

Political boundaries of Achin district in Nangarhar province

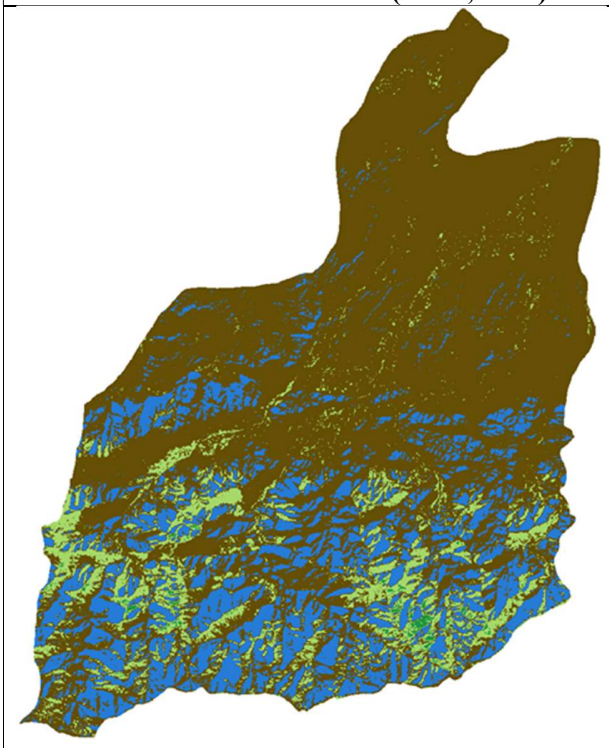
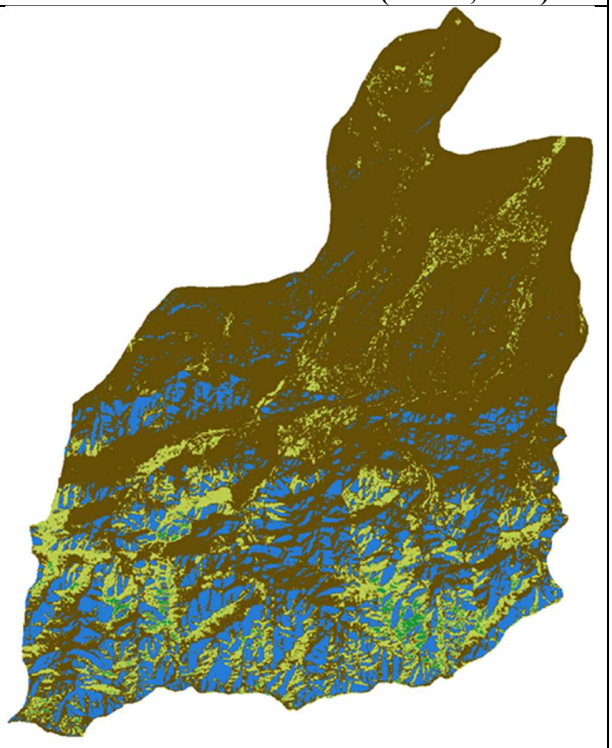
[1] Several options were tried with different NDVI value ranges and different selected months, but this combination seemed to work the best (based on overlap between the opium poppy areas identified using this combination and the opium poppy polygons digitalized by UNODC).

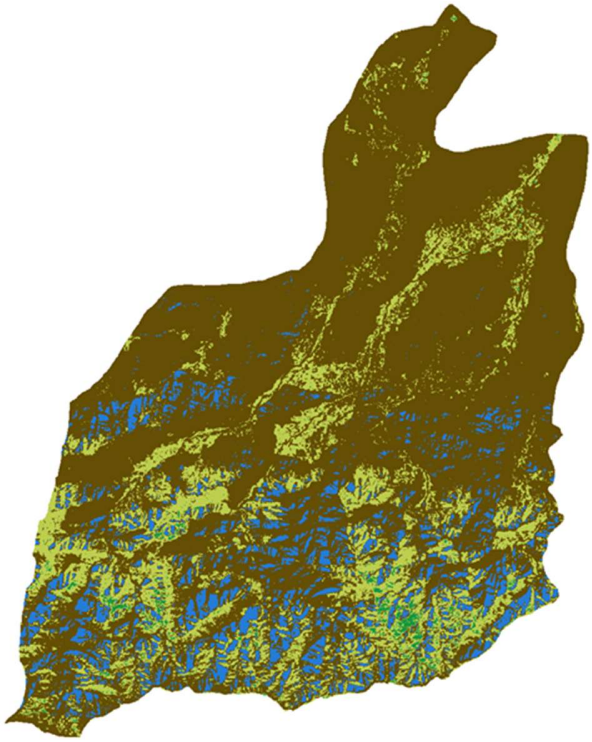
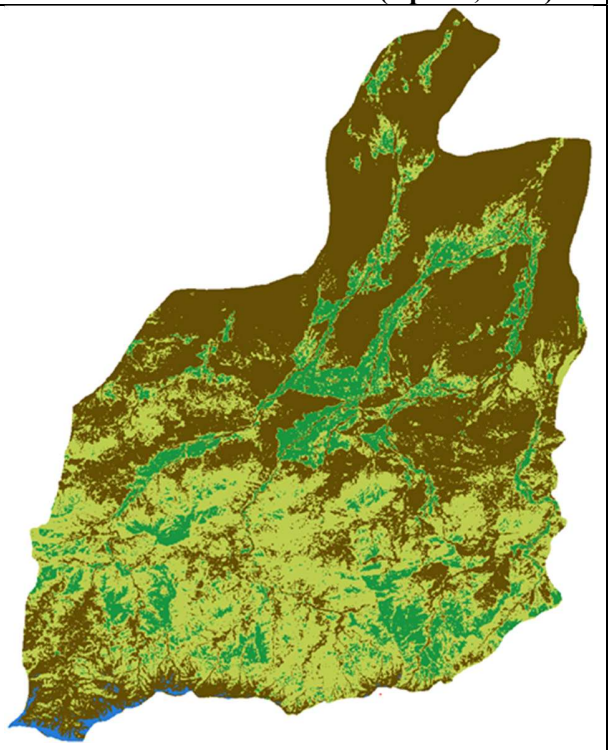
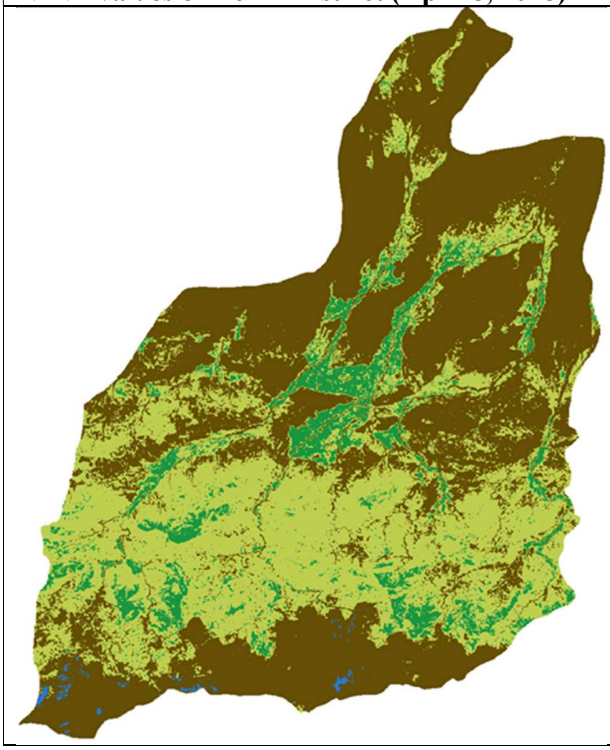
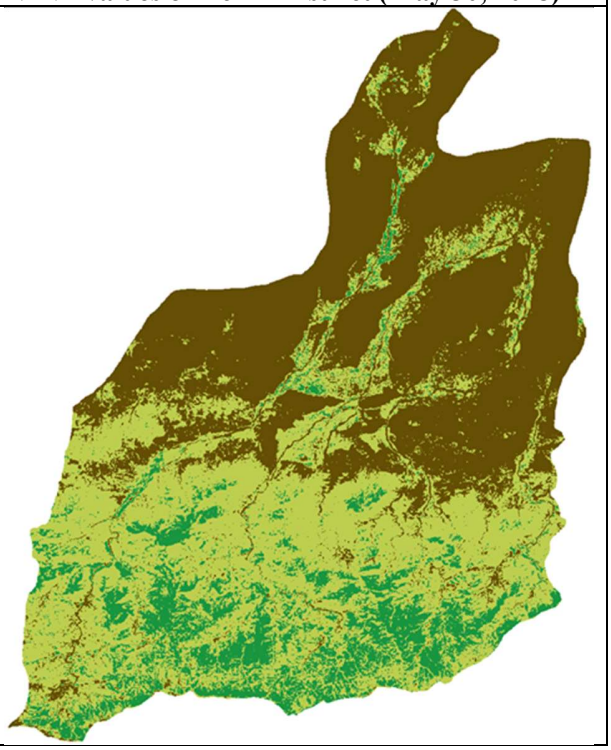
V. Results

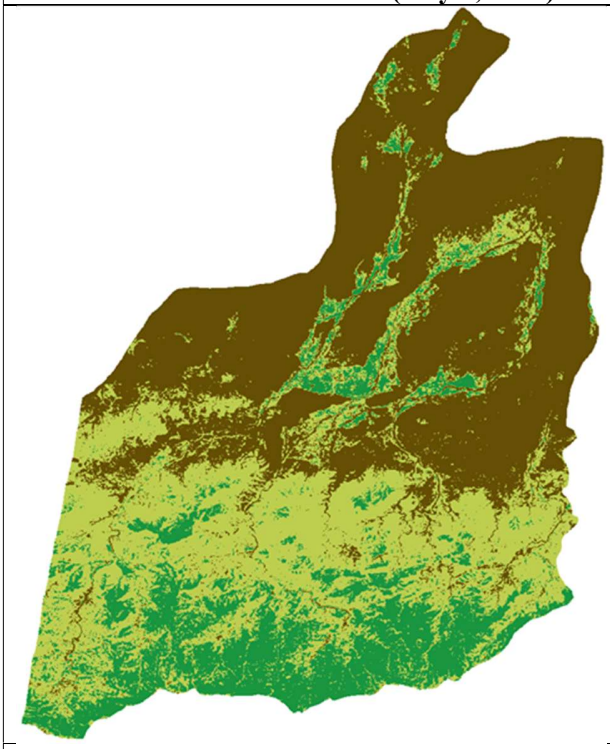
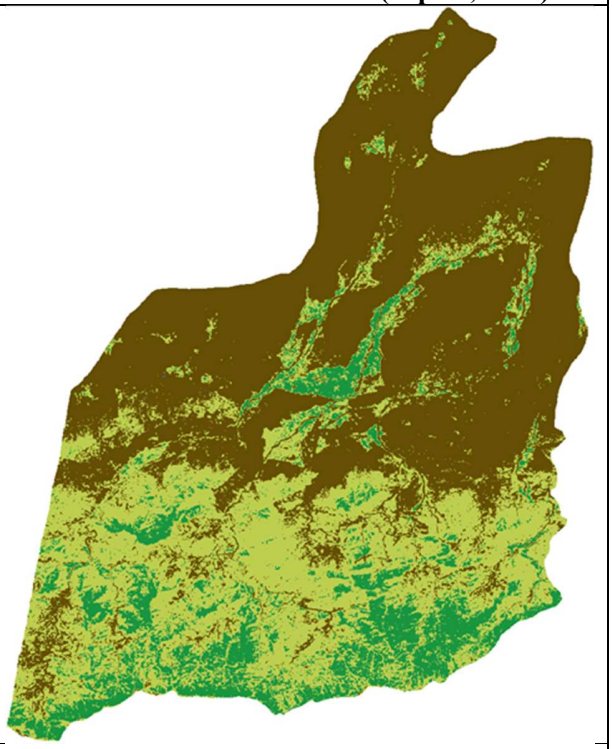
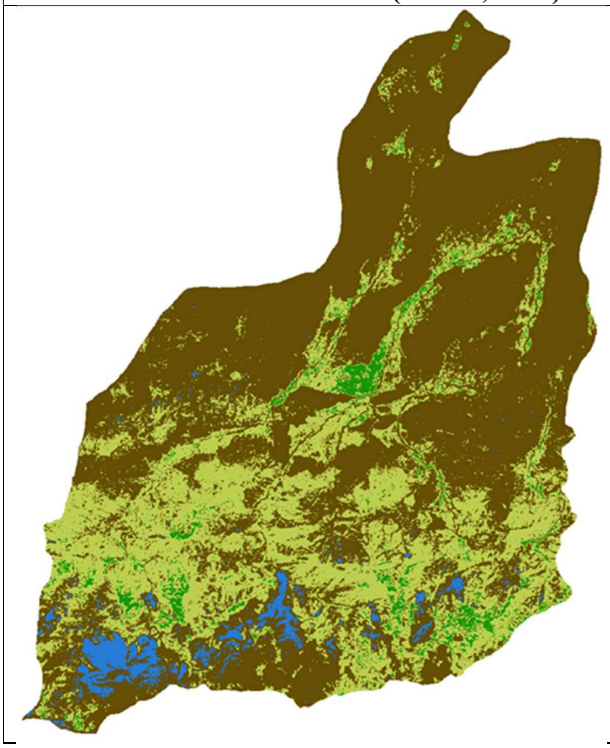
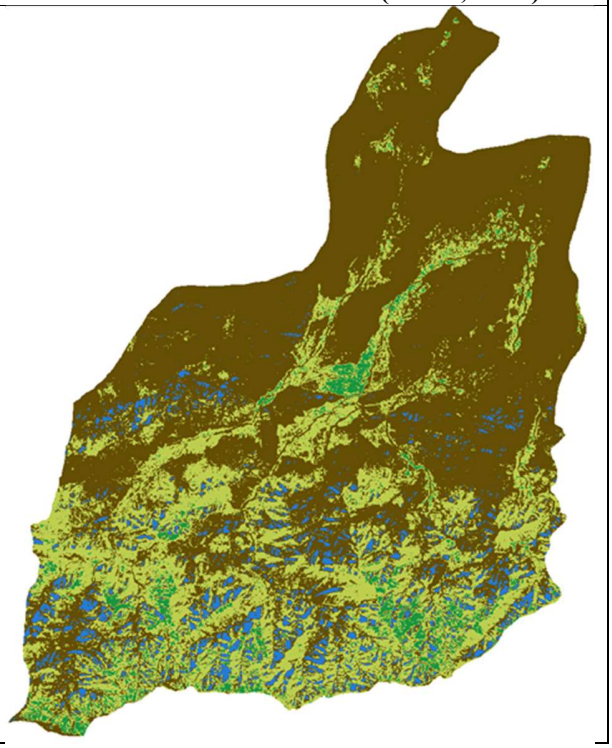
The maps below show the results from the classification, after the pre-processing and processing steps for all the images available in 2018. The meaning of the colors are as follows:

Blue	Water or snow	(NDVI>0)
Brown	(Bare) soil or similar	(NDVI: 0-0.2)
Light green	Vegetation with low or moderate growth	(NDVI: 0.2-0.4)
Dark green	Vegetation with intense growth	(NDVI>0.4)

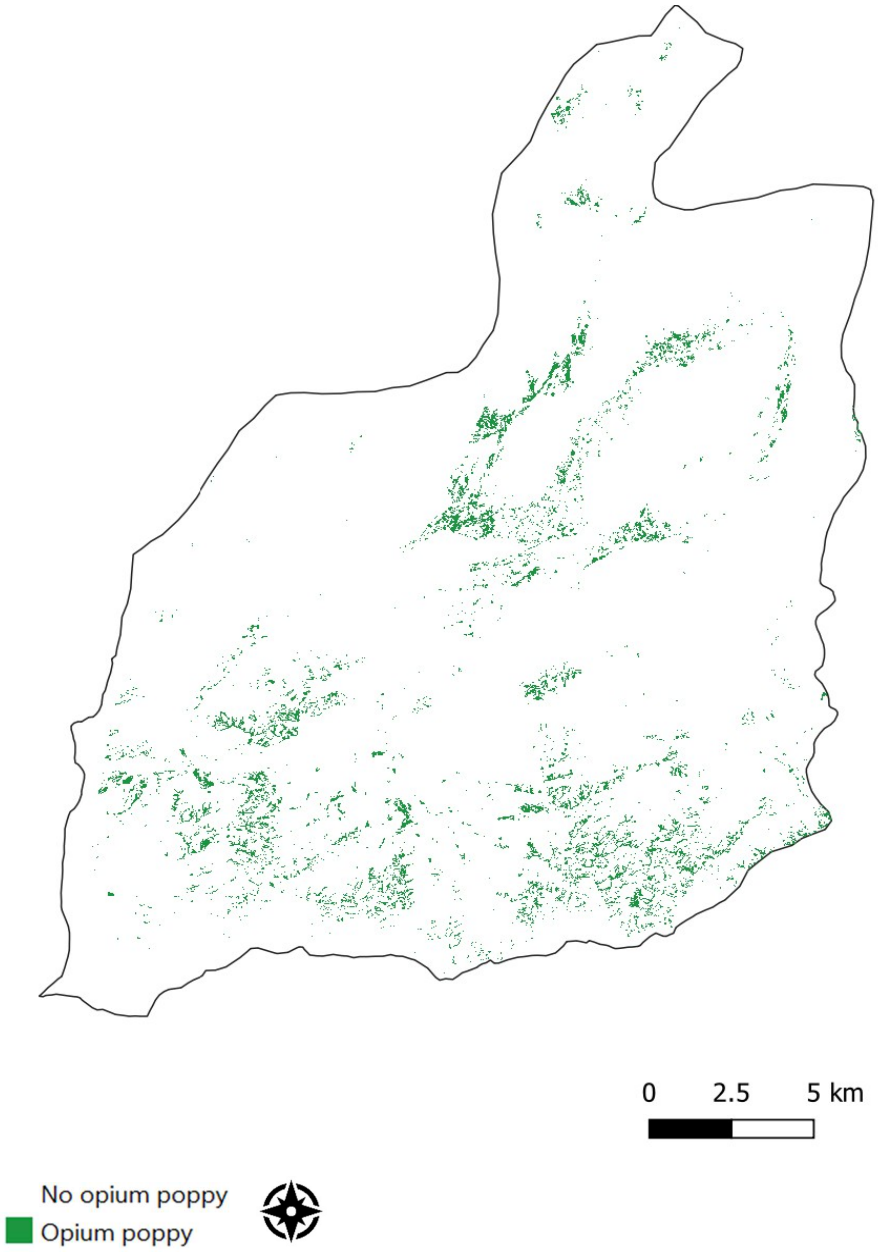
In general, the images showed the expected pattern of some snow cover from October to February with mostly vegetation with low or moderate growth, and then a more predominant cover with intense vegetation from March to September.

NDVI values of Achin District (Jan 6, 2018)	**NDVI values of Achin District (Jan 22, 2018)**
	

NDVI values of Achin District (Feb 7, 2018)	NDVI values of Achin District (Apr 12, 2018)
	
NDVI values of Achin District (Apr 28, 2018)	**NDVI values of Achin District (May 30, 2018)**
	

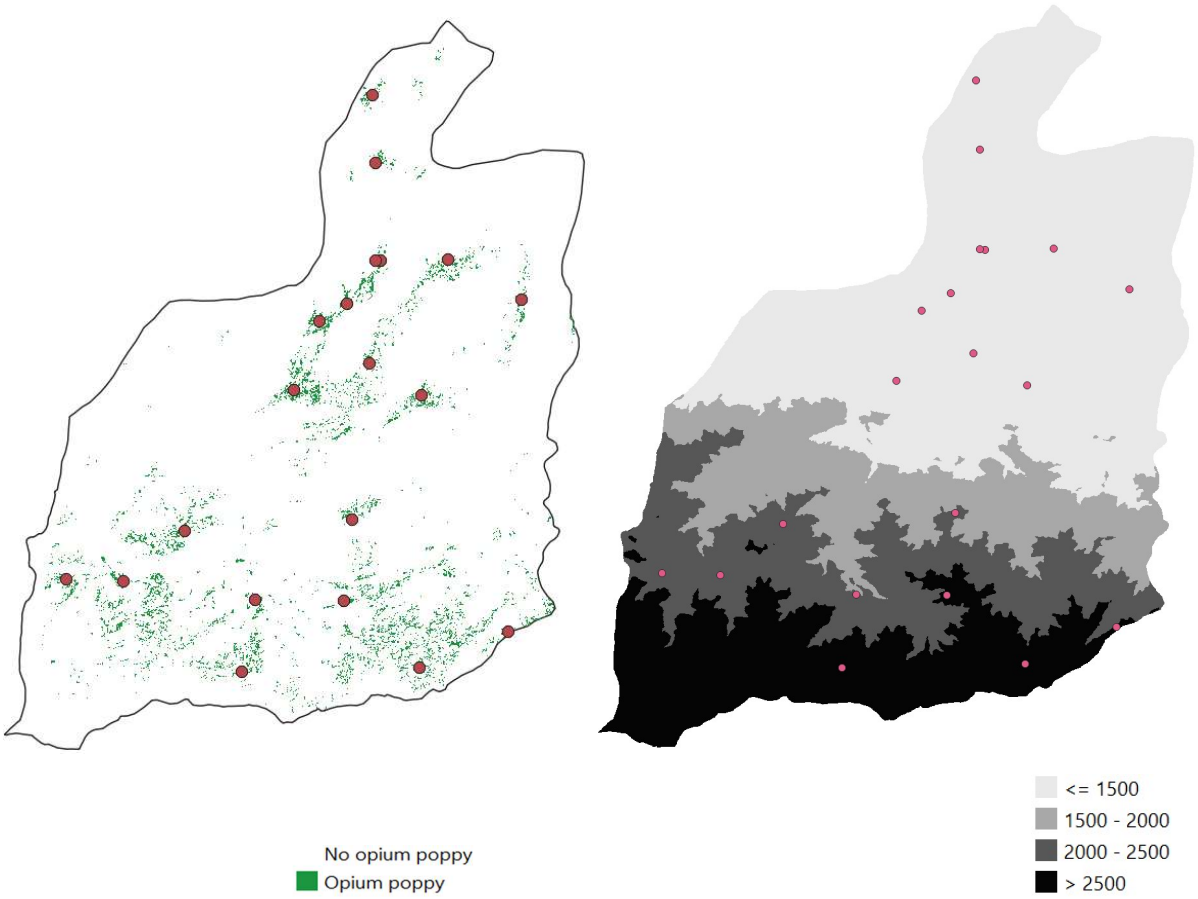
NDVI values of Achin District (July 1, 2018)	**NDVI values of Achin District (Sep 19, 2018)**
	
NDVI values of Achin District (Oct 21, 2018)	**NDVI values of Achin District (Nov 6, 2018)**
	

The final map, after the reclassification step (in which the pixels with NDVI values >0.4 in the classified maps of April 12 and July 1 and between 0.2 and 0.4 in the classified map of November 6 were re-classified as opium poppy) is shown below:



Final opium poppy map

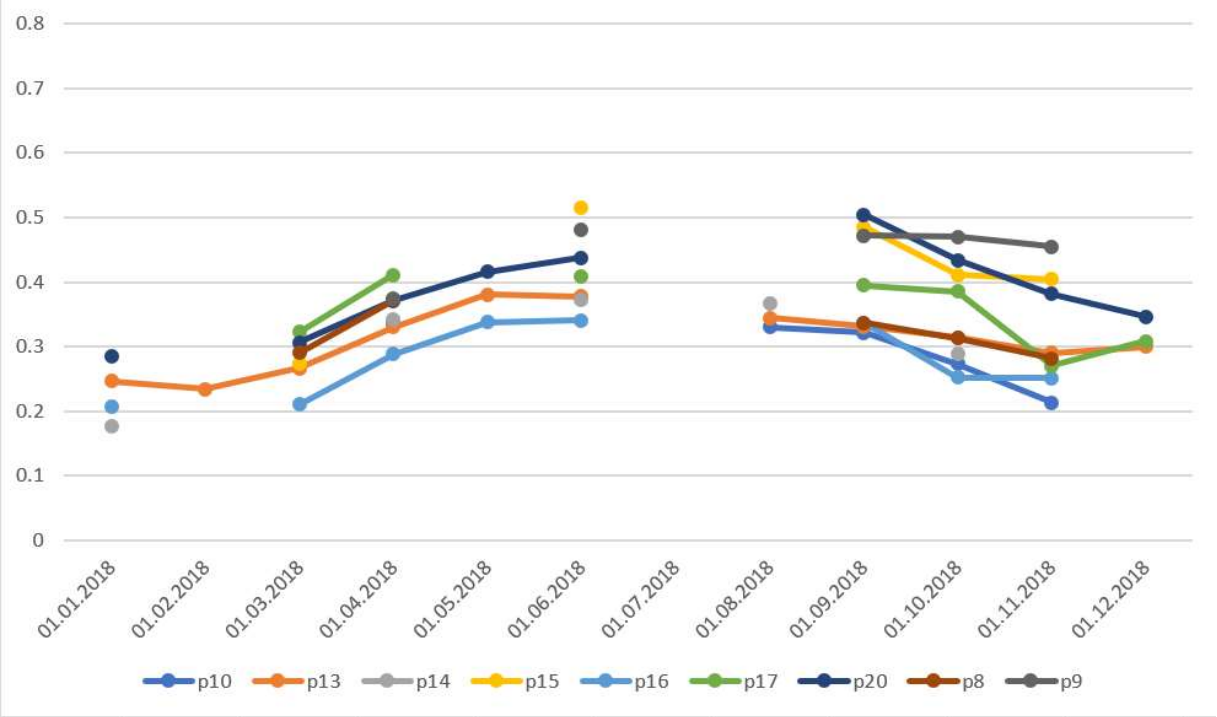
The location of the twenty points (randomly) selected inside opium poppy pixels from the final map that were used in AppEEARS for analyzing the evolution of their NDVI values over time (from January 1 to December 31, 2018) can be visualized in the maps below:



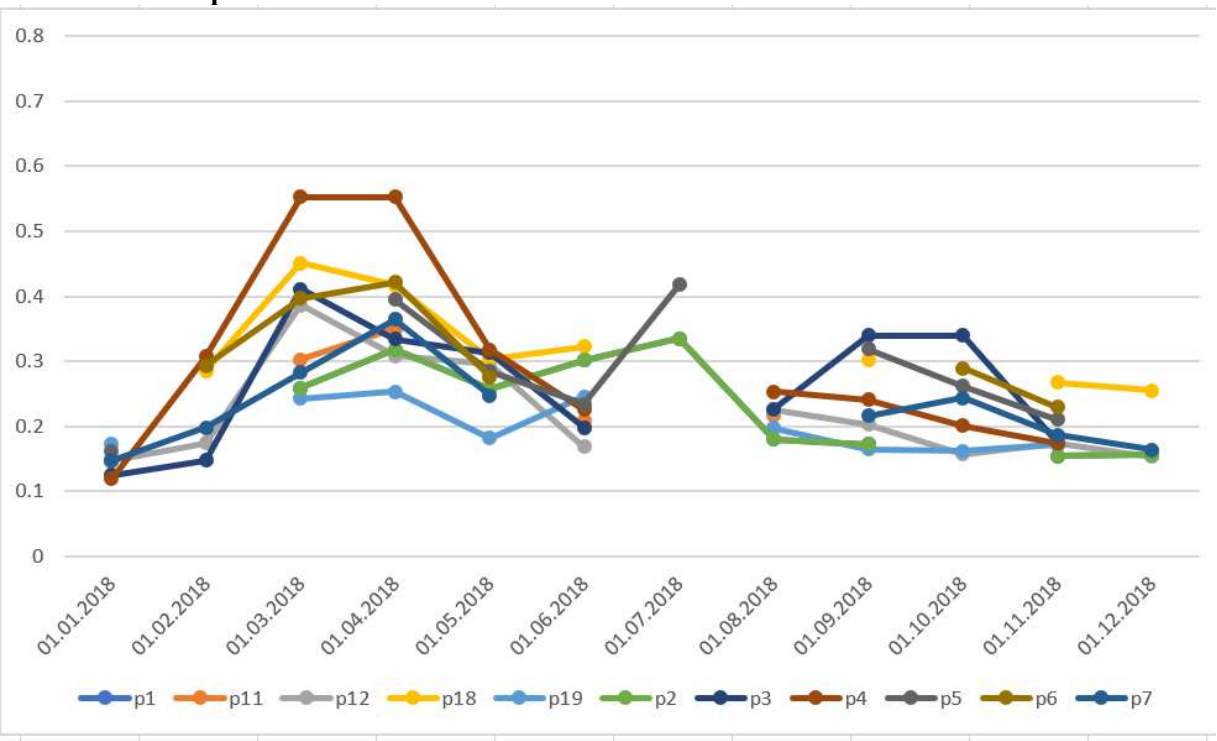
Selected points on final opium poppy map **Same selected points on altitude map (masl)**

The NDVI curves were different according to the altitude. For points located at an altitude higher than 1500 meters, the NDVI curves were relatively similar, but as only the highest quality results were considered, there were many gaps in the data. For altitude lower than 1500 meters, the NDVI curves were less uniform, suggesting that other factors played a (stronger) role on the NDVI values, including irrigation, use of fertilizers, micro-climates, among others. There were many gaps in the data for the points located at this altitude as well.

NDVI curves for points above 1500 meters above the sea level (masl)

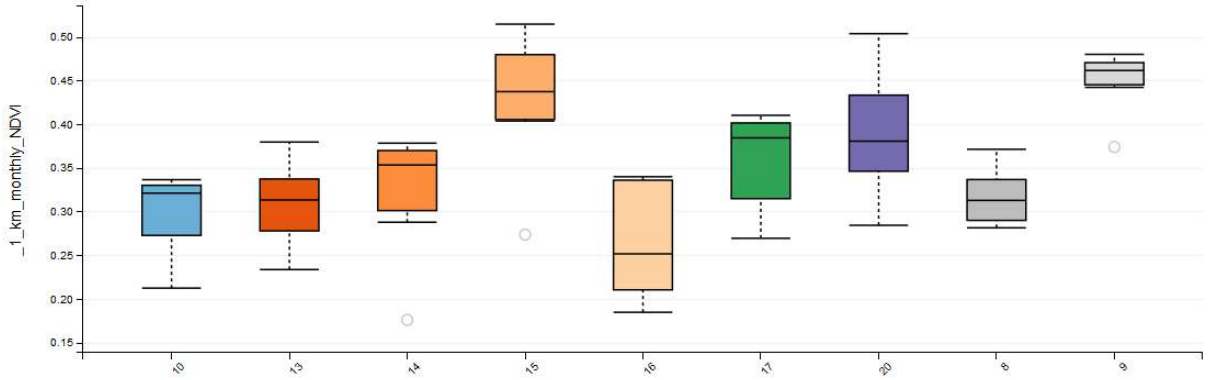


NDVI curves for points below 1500 masl

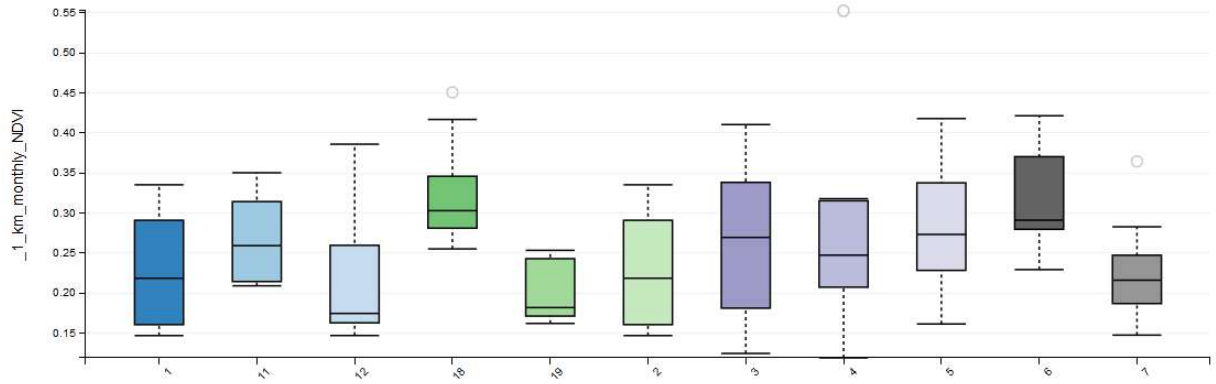


The box plots for those points suggest that at least two of them located above 1500 masl (points 15 and 9) were misclassified as opium poppy, as their NDVI values were high all the year (>0.4). This characteristic may indicate that they are evergreen trees or similar, but as the data is incomplete for some months it is not possible to conclude regarding this issue (see the NDVI curves above showing also the data gaps for those points). In contrast, the box plots for points below 1500 masl seem to suggest that all the selected points corresponded to crops (due to the relatively wide variation of NDVI value over the year) with the exception of point 19, which had a range of NDVI values below 0.25, but as well, as data is incomplete, it is not possible to conclude about this.

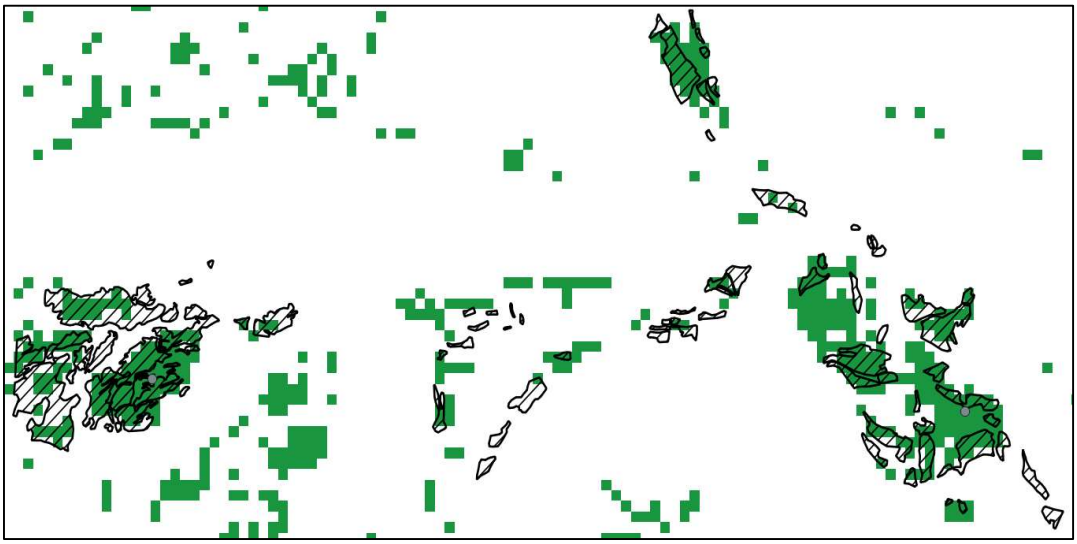
Boxplots for points above 1500 meters above the sea level (masl)



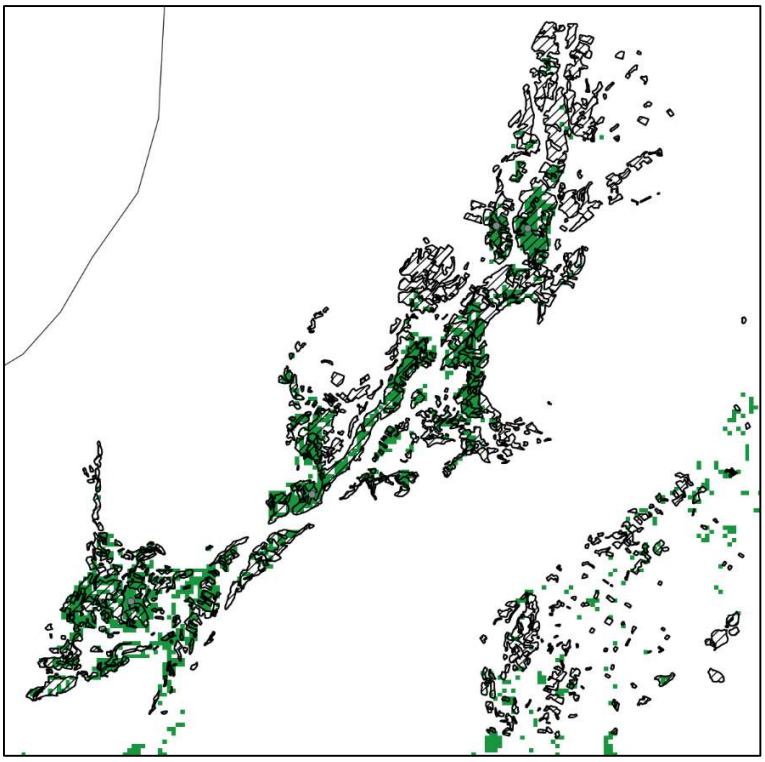
Boxplots for points below 1500 masl



To further check the accuracy of the final map, the opium poppy pixels in the final map were overlapped with the available opium poppy polygons digitalized by UNODC, shown in black with transversal lines, and there was a partial match for both in the upper and lower regions of Achin district.



Overlapping of areas classified as opium poppy in the final map and a sample of opium poppy polygons digitalized by UNODC (altitude above 1500 masl)



Overlapping of areas classified as opium poppy in the final map and a sample of opium poppy polygons digitalized by UNODC (altitude below 1500 masl)

Finally, the sum of the pixel area classified as opium poppy corresponded to 1479.87 Hectares, as shown below

	fid	value	count	m^2
1	1	0	495339	445805100
2	2	1	16443	14798700

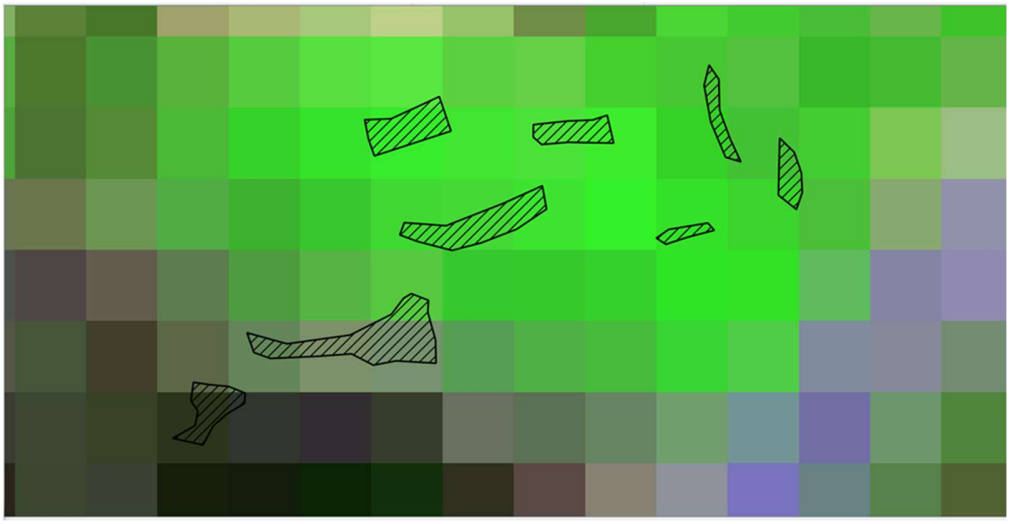
The opium poppy area reported by UNODC for this district in 2018 was 1692 Hectares. Therefore, the total opium poppy area obtained from the final map was only 12.5 percent lower than the area reported by UNODC. This may correspond to a relatively good result, as other authors have found discrepancies of more than 25 percent, as indicated before in this report (Simms, 2016; USAID, 2019), but as the process is time consuming it is not clear if it can be (easily) replicated to larger extensions of Afghanistan.

VI. Discussions, Limitations and Way Forward

The main problem I faced was that unfortunately, for the selected district there were no images available for what it seems to be the actual flowering period of opium poppy. Nevertheless, without opium poppy calendars that also correspond to different altitudes and elevations, it is not possible to know the exact dates. Then I used trial and error to find alternatives, but it was very time consuming.

I also faced a number of issues that may have led to misclassification of opium poppy with other types of agriculture, as it is very difficult to find at unique NDVI pattern for this illicit crop. Among the reasons, beyond altitude and latitude that influence crop calendars, are the opium poppy management practices (e.g., when the planting takes place, if fertilizers and irrigation is used, if there is ploughing after harvest, and whether fields are intercropped or not); and climatic anomalies (e.g., colder spring, hotter summer, drought would result in changes in timing of flowering or harvest) (USAID, 2019).

In the future, I would like to use supervised classification by adding the digitalized poppy polygons by UNODC as training sites in QGIS. I have already tried but it seems that I had a problem with the size of the polygons as many were smaller than one pixel, and the SCP tool simply stopped working (it got frozen even after several attempts).



Visualization of the smaller size of digitalized opium poppy polygons in comparison to one pixel size (Landsat 8)

I also tried with the AppEEARS tools using the digitalized poppy polygons by UNODC to obtain a range of NDVI values for opium poppy, but the NDVI curves did not show a clear pattern, even after separating them by altitude. I assume again there is again a problem with the very small size of opium poppy plots, which are smaller than one pixel (MODIS), and with the mixed pixels, as shown in the visualization above.

I am an economist, so in the future, after obtaining an approximate location of all opium poppy plots in Afghanistan, I would like to add other layers for running geo-spatial regression models to evaluate socio-economic and environmental determinants of opium poppy cultivation in Afghanistan, although this initial step of identifying the location of opium poppy plots is proving to be challenging.

VII. References

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