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The U.S. Government's Global Hunger & Food Security Initiative

MID-TERM PERFORMANCE EVALUATION OF THE REGIONAL AGRICULTURE DEVELOPMENT PROGRAM IN AFGHANISTAN

Estimating Percentage Change in Land Area Under Licit Agriculture in Program Areas

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Estimating Percentage Change in Land Area Under Licit Agriculture in Program Areas

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ACRONYMS

Acronym	Description
DAI	Development Alternatives, Inc.
DAILs	Departments of Agriculture, Irrigation, and Livestock
DO	Development Objective
EQ	Evaluation Question
ET	Evaluation Team
GIS	Geographic Information Systems
GPS	Global Positioning System
HVC	High-Value Crop
IR	Intermediate Result
MCN	Ministry of Counter Narcotics
MODIS	Moderate Resolution Imaging Spectroradiometer
MRI	Moderate Resolution Imagery
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared Spectral Band
OBIA	Object-Based Image Analysis
OLI	Operational Land Imager
RADP	Regional Agricultural Development Program
RADP-E	RADP-East
RADP-N	RADP-North
RADP-S	RADP-South
RADP-W	RADP-West
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UNODC	United Nations Office on Drugs and Crime
U.S.	United States
USAID	United States Agency for International Development
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VHR	Very High-Resolution

ABSTRACT

For the mid-term performance evaluation of the United States Agency for International Development Afghanistan's Regional Agriculture Development Program (RADP) the Evaluation Team (ET) independently assessed the program's influence on reducing land under poppy cultivation. The RADP aims to improve food and economic security of rural Afghans through four projects: RADP-North, RADP-West, RADP-South, and RADP-East. The ET used remote sensing to differentiate between illicit and licit agriculture and quantified the change in area under licit agriculture between pre-program implementation and the evaluation period. The ET used geographic information systems (GIS) data to identify programmatic districts and moderate resolution imagery (MRI) from the Landsat 8 Operational Land Imager and the Thermal Infrared Sensor satellite for comprehensive coverage. To differentiate land cover types, the ET used the Normalized Difference Vegetation Index (NDVI) and seasonal crop management differences. Results indicate that over the evaluated period, the area under poppy cultivation in RADP-South increased by 20 percent. As a percentage of total agriculture, the area decreased from 7.7 percent in 2013 to 7.4 percent in 2017. In RADP-North, the ET calculated a 440 percent increase in poppy production between the two periods—an increase of 2.1 percent in 2013 to 13 percent in 2017. Water availability contributed to increased poppy cultivation, although RADP-North showed evidence of poppy expanding to desert areas. In both RADP-East and RADP-West the area under poppy cultivation decreased by 78 percent and 57 percent, respectively. In both regions, the decline was attributed to environmental conditions more favorable to licit agriculture.

I.0 INTRODUCTION

The Evaluation Team (ET) conducted a performance evaluation to assess the overall progress and accomplishments of the Regional Agricultural Development Program (RADP) to date in four regions of Afghanistan that aimed to improve the food and economic security of rural Afghans. This performance evaluation comes during implementation for the RADP-North and RADP-East regions and at the end of activities for the RADP-West and RADP-South regions. The ET used Earth observation data and GIS analysis to estimate the percentage change in land area under poppy and non-poppy crops in the target areas to answer evaluation question (EQ) 3d (see Table I). The results of the GIS analysis are presented in this document.

All other EQs are answered using a qualitative assessment (see Table I; Conrad et al., 2018). The qualitative assessment identifies achievements, performance issues, and constraints related to implementation and effectiveness of the program. It also identifies results and lessons learned from implementation and provides recommendations to scale up or modify activities. The findings for the qualitative portion are presented in Conrad et al. (2018).

Table I. Evaluation Questions

Evaluation Questions	
A. Implementation	
1.	Is the agribusiness support model likely to be sustainable? a. Are we supporting businesses that largely have good potential for growth? b. Are beneficiary enterprises flexible or adaptable enough to be responsive to market shifts?
2.	Is the training model design and implementation effective in contributing to beneficiary adoption of improved agricultural technologies and licit crops? a. How did selection criteria, curricula, and pedagogy address farmer constraints? b. To what level are the communities being reached (saturation)? c. To what extent does the approach include considerations for varying socioeconomic status among beneficiaries (e.g., security of land tenure, income)?
B. Results	
3.	Based on the implementation approach, status of implementation, and milestones achieved at the time of mid-term evaluation, is there evidence that the program is likely to achieve its results by the end date? <i>Agribusiness model results:</i> a. Are activities creating more market linkages? Are those market linkages more efficient in terms of maximizing returns to the smallholders while meeting the market needs? b. Are beneficiary enterprises more responsive to market demand? <i>Training model results:</i> c. To what degree did beneficiary farmers adopt improved agricultural technologies? d. To what degree did beneficiary farmers adopt licit crops? What was the percentage change in land area under poppy and non-poppy crops in the target areas?
C. Cross-Cutting	
4.	To what extent have women and youth been integrated into the implementation of RADP, and to what extent do women and youth respectively contribute to program goals? a. Which approaches have been most effective in specifically reaching women and youth? b. How have women and youth respectively benefited from RADP implementation, and how are these benefits measured?

c.	Are there any missed opportunities with specifically incorporating women and youth into RADP activities?
5.	Are there any successes from RADP that can be adapted to specifically integrate women and youth?
D. Thematic	
6.	Is the regional approach to the RADP programming likely the most effective for achieving program goals? For example, how might a regional approach compare to a commodity-specific approach?
7.	To what extent will institutional and informational structures be sustainable after project implementation?

The next section provides a brief review of previous work used to identify and quantify illicit production of poppy crop in Afghanistan using remote sensing techniques and imagery, followed by sections on the methods used, the results of the ET analysis, and finally a discussion and comparison to other work.

2.0 BACKGROUND

RADP Background

The United States Agency for International Development (USAID) funds RADP, the umbrella program in Afghanistan, with a budget of just over \$241.7 million and operations in 4 regions across 21 provinces and 116 districts. The program is run as four separate regional projects: RADP-North, RADP-West, RADP-South, and RADP-East (implementation areas shown in Table 2 below).

Table 2. RADP Characteristics

Area	RADP-North	RADP-West	RADP-South	RADP-East
Award number	306-C-14-00002	306-C-14-00007	306-C-13-00018	306-C-16-0001
Award date	May 15, 2014	August 10, 2014	October 2, 2013	July 2016
Activity end date	Anticipated May 2019	September 27, 2016 ^a	October 2017*	July 2021
Funding amount	\$78,429,714	\$27,658,205	\$107,621,129	\$28,000,000
Activity funding	AG 75%, AD 25%			
Implementing organization	Development Alternatives, Inc. (DAI)	Chemonics International, Inc.	Chemonics International, Inc.	DAI
Subcontractors/grantees	ACDI/VOCA, Alcis, Development and Training Services, Inc., Dutch Committee for Afghanistan, Joint Development Associates, Pax Mondial Risk Management Company, [REDACTED], [REDACTED], Afghan Public Protection Force	Agency for Rehabilitation and Energy Conservation in Afghanistan, Coordination of Humanitarian Assistance, Dutch Committee for Afghanistan, Equal Access, Services International LLC, Afghan Public Protection Force	Afghan Development Association, Dutch Committee for Afghanistan, Equal Access	Organization for Sustainable Development and Research, Relief International, Crimson Capital and Mondial Risk Management Company
Province coverage	Badakhshan, Baghlan, Balkh, Jawzjan, Kunduz, and Samangan	Herat, Farah, and Badghis	Kandahar, Helmand, Uruzgan, and Zabul	Kabul, Nangarhar, Laghman, Ghazni, Logar, Wardak, Parwan, and Kapisa
Targeted value chains	Wheat, livestock, high-value crops			Livestock, high-value crops

^a. Terminated for convenience.

Working in alignment with Government of Afghanistan goals and the Ministry of Agriculture, Irrigation, and Livestock as well as the Departments of Agriculture, Irrigation, and Livestock (DAILs) at the subnational level, RADP aims to improve the food and economic security of rural Afghans. The program's development hypothesis is that if all value-chain actors have access to appropriate training, information, inputs, and technology within a more competitive, efficient, and profitable agricultural value chain as well as a conducive policy and regulatory environment, they will increase their incomes and food security.

Each RADP activity employs a value-chain facilitation methodology that works in all segments of agriculture supply chains from the farmers (i.e., producers) to the consumers, addressing bottlenecks in

each targeted value chain. Specifically, activities focus on improving productivity of wheat, investment in and production of high-value horticultural crops (e.g., grapes, raisins, pomegranates, stone fruits, nuts, vegetables), and production of livestock (see Table 3 below). Increasing women’s participation in and benefit from the agricultural sector is a critical component of each activity. To develop targeted value chains, RADP activities are strengthening relationships and trust among private sector entities. Each RADP also focuses on critical cross-cutting themes such as on-farm water management, nutrition, alternative development, finance, and support for DAILs. Another cross-cutting theme is to strengthen the enabling environment to support strengthening the private sector by promoting an improved legal and regulatory framework, and by using policy advocacy and dialogue to strengthen the private sector via a mix of direct implementation and a \$10-million grant fund for each RADP. These enabling environment activities were led by the RADP-South region until its termination, and after an interlude, was taken up by the RADP-North region. Table 2 shows how intended (cross-cutting) outcomes of the program will lead to an Intermediate Result (IR), Sub-Intermediate Results (Sub-IRs), and finally to the Development Objective (DO) to expand sustainable, agriculture-led economic growth.

Table 3. RADP Results Framework

DO 1: Sustainable, Agriculture-Led Economic Growth Expanded		
<i>IR 1.2: Vibrant and prosperous agriculture sector developed</i>		
<i>Sub-IR 1.2.1: Productivity of key agriculture crops increased</i>		<i>Sub-IR 1.2.2: Commercial viability of agribusinesses increased</i>
<i>Outcome 1: Increased agriculture sector productivity and profitability in target region</i>	<i>Outcome 4: Increased and sustained adoption of licit crops</i>	<i>Outcome 2: Increased profitability of small, medium, and large agribusinesses</i>
<i>Cross-Cutting Outcome 3: Increased women’s participation in agriculture value-chain activities</i>		
<i>Cross-Cutting Outcome 5: Improved enabling environment for farmers and agribusiness</i>		

While each regional project uses similar approaches—blending direct technical assistance and training with strengthening value-chain linkages—variation in climate, capacity, security, and shifting government priorities have led to minor differences in activity implementation. The RADP-South, RADP-West, and RADP-North regions provide technical assistance to wheat producers and value-chain actors, whereas the RADP-East region does not focus any of its activities on the wheat sector. All four RADPs support producers and value-chain actors of high-value crops (HVCs), but specific crops vary widely by regional climate. Likewise, all RADPs support livestock value chains, but the challenges for different species vary widely by region. RADP-South put relatively more resources toward supporting veterinary units than the other regions. Although not explicit in the design phase of all RADPs, providing opportunities for licit farming and employment became a government and donor priority over the course of implementation, particularly for the RADP-South region, which was active in areas traditionally known to be the most active in poppy production. The RADPs aimed to provide opportunities to encourage farmers to shift from illicit crops to licit crops by improving farmers’ abilities to produce HVCs and livestock products and by facilitating market linkages to increase their product sales.

2.1 LITERATURE REVIEW

In this analysis, the ET used a combination of remote sensing analysis with GIS to differentiate between illicit and licit agriculture and quantify the change in illicit agriculture between pre-program implementation and the evaluation period for participating districts in the four regions. Previous efforts to use remotely sensed imagery to quantify the production of poppy and non-poppy agriculture are discussed below, with a primary focus on methods that use moderate resolution imagery for

comprehensive coverage across Afghanistan rather than a sample-based approach using very high-resolution imagery in limited areas and extrapolation to the wider region.

2.1.1 Previous Research

The work by Sader (1990) represents one of the first detailed assessments of the ability to detect and quantify poppy crops using satellite imagery. Sader noted that detailed mapping had never been attempted in any country, although two pilot projects using satellite imagery for monitoring poppy had been conducted—one in Thailand and one in India. However, Sader's work laid the groundwork in detailing the data and methods needed to support such an analysis. This included the need for "good quality" multispectral satellite data [such as SPOT and the Landsat Thematic Mapper (TM)], a regional crop calendar (detailing the flowering and post-harvest periods and taking into account regional and environmental differences), ground-truthed samples roughly coinciding temporally with satellite imagery acquisition dates, and fields of sufficiently large size and with minimal intercropping to avoid having the pixel straddle different fields or land cover types (resulting in a "mixed pixel" spectral signal).

In terms of the crop calendar, Sader (1990) noted that poppy in the Southern region of Afghanistan is planted in the fall, flowers in March or April—with the flower phase lasting two to three weeks—and harvested between mid-April to early May. He also noted that the crop calendar varies strongly with altitude and region.

Sader (1990) suggested a combination of different classification techniques: a supervised classification using field samples from multiple types of crops, co-located with the imagery as training samples to identify pixels with similar spectral signals; and an unsupervised classification separating agricultural lands from other land cover types. Sader also suggested that signatures needed to be developed independently for each satellite image (i.e., scene) due to variation in vegetation conditions and imagery properties.

Building on the work of Sader (1990), Simms (2016) evaluated different alternative methods used by the United Nations Office on Drugs and Crime (UNODC) and the United States (U.S.) Government to monitor poppy production in Afghanistan. His extensive research included descriptions of sampling techniques using very high-resolution (VHR) imagery extrapolated to the wider region as well as a comprehensive classification across Afghanistan using low-resolution imagery.

Simms (2016) examined the spectral profiles of reflectance values from homogenous ("pure") samples of poppy, alfalfa, and wheat, noting that there is good separation between the crops within certain wavelength ranges ("bands"), which could be used to differentiate between the crops from remotely sensed imagery. However, he described various factors that can cause deviation from this ideal, including pixel resolution, crop spacing, temporal factors such as image acquisition date and frequency of imaging, radiometric resolution, and atmospheric conditions and corrections of the imagery.

Simms (2016) described a number of previous attempts to quantify poppy from satellite imagery, including different resolutions. Ultimately, he summarized three key factors that are needed for a robust analysis: the timing and revisit¹ time of imagery, the resolution of the imagery, and the use of supporting ancillary data.

Simms (2016) evaluated the potential of using lower-resolution imagery for country-wide assessments of poppy crops. His evaluation used Moderate Resolution Imaging Spectroradiometer (MODIS) 250-meter resolution imagery for classification of poppy using Normalized Difference Vegetation Index (NDVI) values. NDVI values are an indication of the amount of chlorophyll content in the vegetation and therefore can be used to indicate the relative degree of plant vigor.

¹ The frequency that imagery for the same location is captured.

To better understand the geographical relationship between NDVI values and crop cycles, Simms (2016) collected hundreds of images across the country, ranging from VHR to lower-resolution imagery. From this effort, he obtained spectral profiles from irrigated and non-irrigated areas through time to identify distinct temporal cropping patterns and associated NDVI values. In Helmand Province, cropping patterns indicated two crop cycles for cereal crops (e.g., wheat, barley, oats), while poppy is only green in the first cycle, as it is not suited for late summer heat. Additionally, he found NDVI values before February were very low. By March, poppy and wheat both have stem elongation and therefore higher NDVI values. By early April, poppy and cereal crops both start flowering. Peak NDVI values were found to correspond to around the end of poppy flowering. However, Simms noted that the flowering itself was not observed in the MODIS 250-meter spectral values due to the coarse pixel size (i.e., the flowering signal represented a small portion of the reflectance value). After opium harvest, poppy plants quickly dry and die back and by early June, poppy locations had very low NDVI values, while there were higher values for the other crops.

However, Simms (2016) also noted that there is wide variation in NDVI values of agriculture due to differences in latitude and elevation that control the timing of crop cycles, including a two-month difference in first-peak NDVI between adjacent valleys in Badakhshan Province, due to differences in elevation. Lastly, Simms also noted the sizeable NDVI variations annually (especially in the Northern region) in dryland crop production due to periods of drought, disease, or cooler spring conditions, which affect factors such as the date of green-up and senescence, as well as the establishment of plants. This latter thereby lowers the NDVI value within a pixel due to mixes of bare ground and canopy cover. Conversely, he found higher NDVI values in some of the higher valleys with good water supply.

Because of the importance of the date of the imagery and the difficulty in finding comprehensive cloud-free imagery within a specific time window, Simms (2016) also examined the potential of using 16-day composited imagery from MODIS—with the pixel value representing the highest NDVI value from the image stack. However, he found that the composite imagery masked some of the variation that is important (e.g., changes in plant phenology), especially given that the flowering period of poppy is only two weeks. Simms therefore decided against this approach.

Lastly, because of the coarse resolution (250 meters) of MODIS imagery and the fact that field sizes are commonly less than one hectare in size, Simms (2016) evaluated the impact of different mixes of crops within a single pixel on resulting NDVI values. To do so, Simms generated annual spectral profiles of NDVI values derived from MODIS data for three years and highlighted the variation in NDVI values across those years. His findings showed that different mixes of poppy, non-poppy agriculture, and barren lands effect both the timing and magnitude of the pixel NDVI values.

Curran et al. (2013) examined the potential of using object-based image analysis (OBIA) techniques to identify different crop types from VHR multispectral imagery. Their study utilized Quickbird high-resolution (2.8 meters) multispectral imagery along lands adjacent to the Helmand River within Helmand Province in mid-April 2008 (noting that this was the best period to differentiate poppy from other crops). Realizing the difficulty in identifying crops by the spectral signature alone, they included additional characteristics of poppy crops to improve their outcome. For example, they noted that the poppy canopy is non-continuous with gaps between plants exposing soil, while other crops such as wheat have a more continuous canopy that results from broadcast seeding. While these textural differences are too fine to pick up through moderate resolution imagery such as MODIS (250 meters) or Landsat (30 meters), they are identifiable using high-resolution imagery. The Curran et al. team noted that for high-resolution imagery, OBIA was shown to produce more accurate classification than traditional pixel-based classification approaches.

Curran et al. (2013) used an OBIA approach to feature extraction. The analysis first segments the image into objects, and then the software calculates various attributes (spectral, textural, etc.) for each object. The feature extraction tool allows image classification using either a supervised or rule-based approach.

In the supervised approach, the user selects individual objects to guide the software for classification parameters, while the rule-based extraction allows the user to manually select classification parameters. These parameters include band minimum/maximum/average, area, compactness, roundness, elongation, convexity, rectangular fit, texture mean/range/variance/entropy, hue, intensity, and NDVI.

For the supervised classification, Curran et al. (2013) used 110 samples for poppy, 120 samples for wheat, and 55 samples for other agriculture. However, they noted that even in this small study area they did not have enough ground reference samples to be statistically valid for an accuracy assessment. They used crop type maps from aerial imagery and discontinuous ground reference information for their ground-truthed information, which they used for both training and accuracy assessments.

Curran et al. (2013) noted a difference of about 13 percent of the amount of land classified as poppy between the two approaches. Their accuracy assessment showed there was low accuracy using either the traditional supervised (50 percent overall accuracy) or rule-based (47 percent overall accuracy) classification techniques without OBIA. The overall accuracy improved by incorporating OBIA into either approach: 76 percent for the OBIA supervised approach and 73 percent for the OBIA rule-based approach. However, the kappa coefficients (a statistical test to show agreement between reference and classified data) for OBIA are low to moderate—therefore the confidence in the accuracy for either method is low. It is also important to note that Curran et al. (2013) conducted their analysis for a single time period rather than taking seasonal approaches used by others.

Finally, the Ministry of Counter Narcotics (MCN) and the UNODC conduct annual surveys of the location and extent of poppy production across Afghanistan. The UNODC 2017 report shows the annual amount of poppy production from 1994 to 2017. They have used remote sensing in their estimates since 2002, though the methods have changed over the years. Since 2015, they have used a combination of approaches based on the location of likely poppy production by area. In provinces where the most poppy is found, they use a sampling approach; in provinces with a low level of poppy production, they use a targeted approach using full coverage of satellite imagery for portions of the province. In provinces with no indication of poppy cultivation, they use a village survey approach. For 2017, out of the 34 provinces, 15 were sampled, 13 were targeted, and 6 were considered poppy-free. They note that their criteria for being poppy-free is any area with less than 100 hectares of opium poppy cultivation. In all locations where the sampling approach was used in both 2016 and 2017, the same sample locations were utilized to maintain consistency. While some provinces had increased poppy production, the methodology change (from a targeted approach in 2016 to a sampling approach in 2017) could have influenced the results.

The UNODC 2017 sampling regime was changed after 2015 from using 10-kilometer by 10-kilometer grids to 5-kilometer by 5-kilometer grids. The final sampling frame used was composed of 6,498 cells from which images were randomly selected. The domain of the sample area consisted of both irrigated and non-irrigated lands and represented approximately 38 percent of the total potential agricultural lands within the 15 provinces that used the sample approach. In addition, they excluded any lands less than 0.25 square kilometers from the sampling domain to reduce the chance of selecting sampling cells with low amounts of arable lands. The sample size was determined by the number of available images, the number of provinces, and the agricultural area of the province. In addition, they set the sample size to no fewer than 20 samples per province. In total, the 2017 report relied on VHR imagery for 673 5-kilometer by 5-kilometer grids over the 15 provinces.

The UNODC 2017 report relied on satellite imagery following a crop calendar aligned to the flowering phase and the post-harvest phase, noting that poppy is plowed immediately after harvest whereas wheat fields are not. As such, they utilized imagery in the RADP-South, -East, and -West regions from March or April; and used imagery in May, June, or July for the RADP-North region. They then used imagery approximately two months later for the second date imagery. They used visual interpretation to delineate opium poppy fields from 0.5-meter resolution (pan-sharpened) PLEIADES multispectral

satellite images covering a 5-kilometer by 5-kilometer area. They combined that with ground-truth information from maps, global positioning system (GPS) points, ground photographs tagged with latitude and longitude coordinates, and visual interpretation of the second-dated images to differentiate poppy from other crops. The visual interpretation was based on a combination of natural color and false-color infrared. They also had 1,854 GPS points for poppy fields with pictures. UNODC researchers also noted that they had some difficulty getting images for the dates needed given cloud cover.

Finally, the UNODC 2017 report used a statistical relationship based on the ratio of poppy to potential agricultural land—taking into account different sampling regimes for the different provinces. In their quantification, they report at the 95 percent confidence level. An examination of the results shows a wide range (up to 6.7 times) between the low and high estimates of poppy area (at the province level). However, overall the average of the 15 sampled provinces had an average of 1.7 times the difference and only 1.2 times the national level (which included the target provinces). As with other researchers, UNODC was unable to conduct an accuracy assessment due to security conditions that prevented the collection of the number of reference samples needed for a valid assessment.

In the targeted provinces (areas with little poppy production), UNODC relied on a surveillance system and information from village “headmen” within the provinces to identify poppy production locations. Field crews also visited potential poppy sites and collected GPS coordinates for those confirmed locations, which were used for reference samples. Imagery was collected for areas of concentrated poppy production. They used the poppy classified area in the imagery for the total estimate of poppy cultivation. UNODC considered these estimates minimums as some areas would undoubtedly be missed.

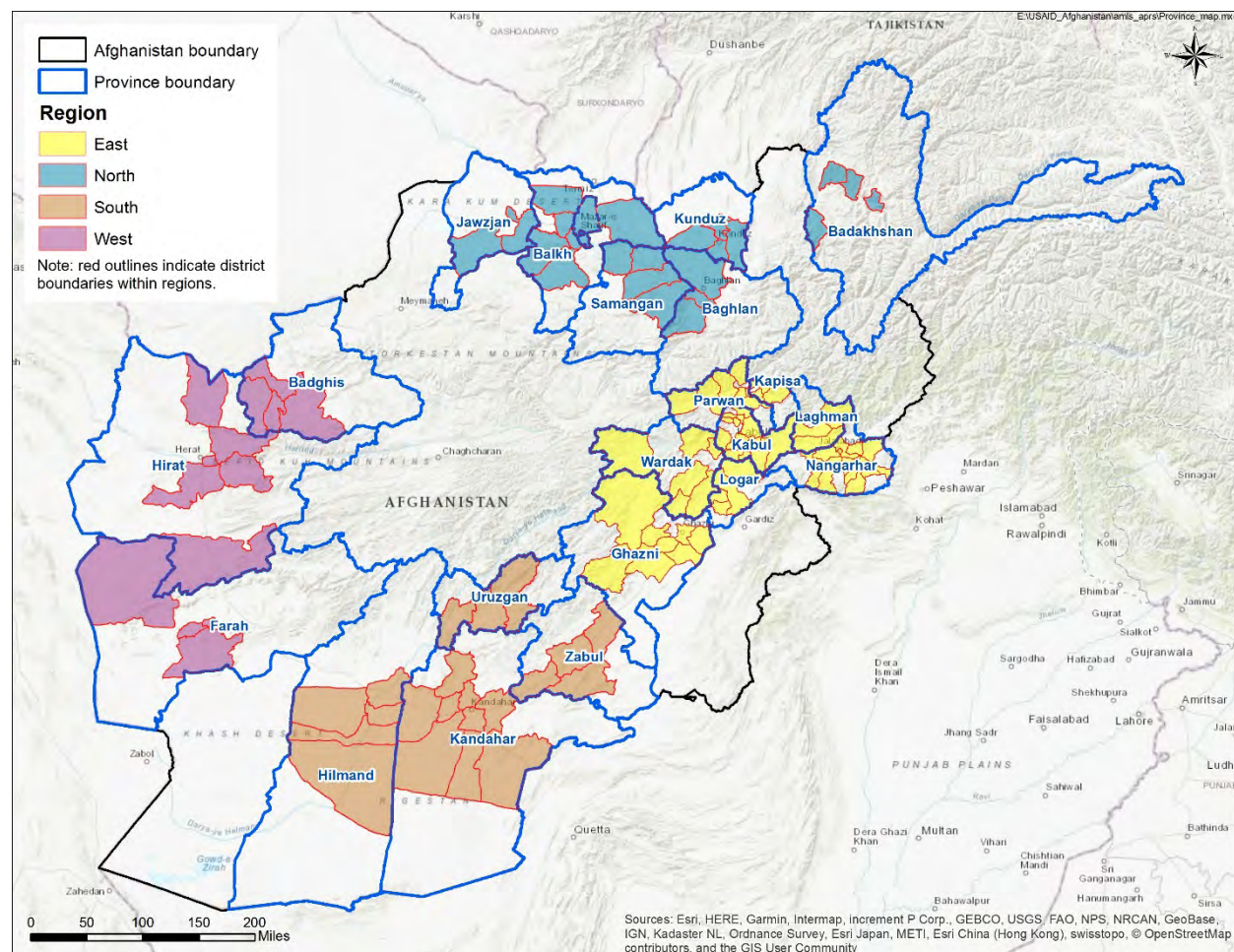
3.0 METHODS

3.1 GENERAL APPROACH AND DOMAIN

As noted above, other researchers such as UNODC have used a statistically based approach to estimate the area under poppy cultivation drawn from a set of sample locations within the study area domain. In their analysis, they utilize a select set of high-resolution images aligned with field-referenced data for their classification and then extrapolate the results to the broader region. In contrast, in this analysis the ET used a non-statistically based approach to classify moderate-resolution imagery covering the entire study domain. The ET's basis for this approach is described in more detail below.

While the imagery available covers the full extent of the RADP regions, the ET limited their estimation of poppy cultivation to a subset of districts within the four regions that participated in the program. This represents 21 provinces out of a total of 34 provinces in Afghanistan. Figure 1 shows the districts the ET examined as well as the subset of districts within those provinces.

Figure 1. Geographic Extent of the Four RADP Programmatic Regions and Districts Examined



Boundary data source: ESRI, 2018a.

To assess the potential impact of the program on poppy production, the ET classified the landscape into poppy, non-poppy agriculture, and other land use types for each of the RADP programmatic areas. The pre- and interim evaluation dates for each region are listed in Table 4.

Table 4. Pre-Implementation and Evaluation Periods for Each RADP Region

Region	Pre-Implementation Period	Evaluation Period
North	2013	2017
South	2013	2017
West	2014	2017
East	2015	2018

3.2 SATELLITE IMAGERY

As noted above, the ET used moderate resolution imagery in this analysis. As such, they utilized imagery from the Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite.² The Landsat imagery is available cost-free from the United States Geological Survey (USGS) (<https://landsatlook.usgs.gov>) and covers all of Afghanistan from February 2013 to the present. Each scene (i.e., individual image) covers a swath of approximately 17 kilometers north-south by 183 kilometers east-west and contains 11 bands: eight spectral bands (bands 1 to 7 and 9) at 30-meter resolution (30 by 30-meter pixel), one panchromatic (band 8) at 15-meter resolution, and two thermal infrared bands at 100-meter resolution. Additionally, each scene was radiometrically calibrated and corrected for terrain displacement (i.e., orthorectified) and therefore can be used directly for surface reflectance analysis.

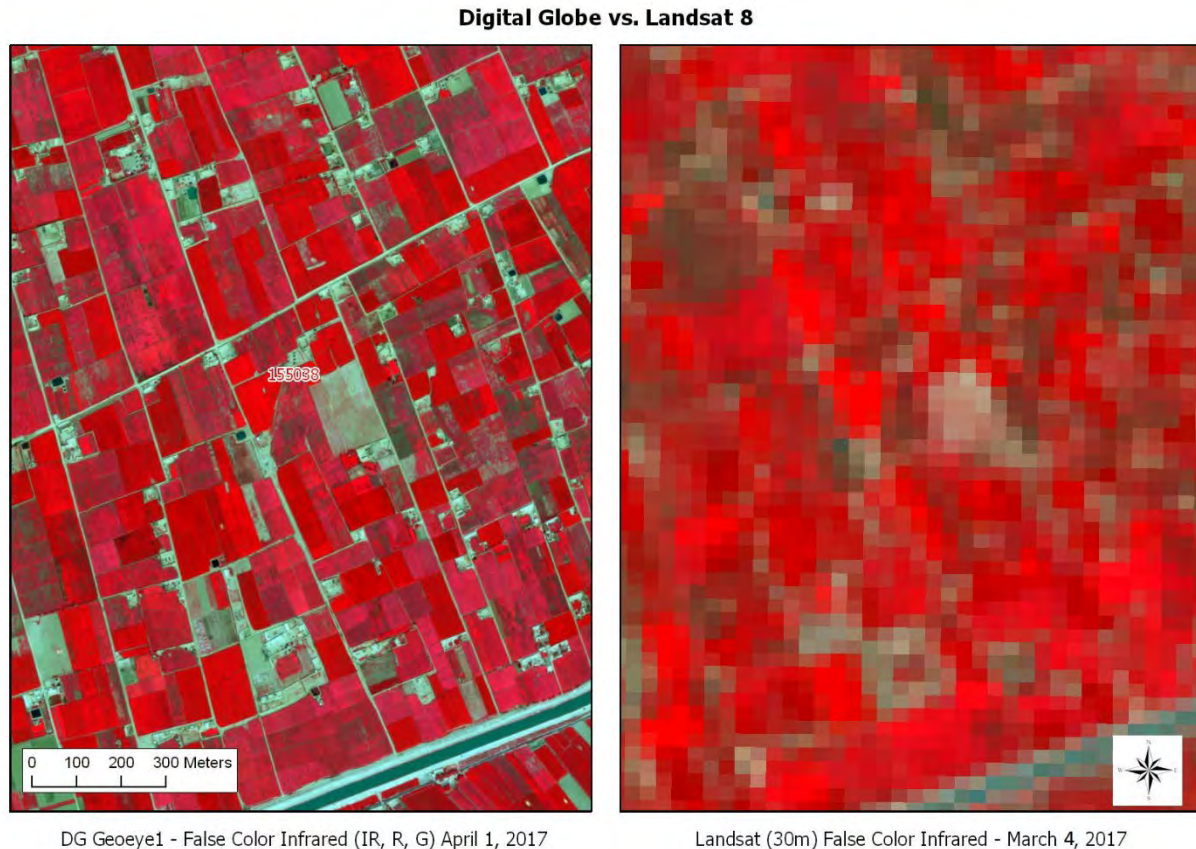
In contrast to Landsat data, high-resolution imagery is available from Digital Globe extending back to 1999. Digital Globe provides access to multi-spectral imagery across Afghanistan at resolutions from sub-meter to approximately 2-meter resolution from their archives. Depending on the specific satellite, one panchromatic and four to eight bands of multispectral imagery are collected covering the visible and near-infrared portion of the electromagnetic spectrum, which is consistent with the bands that are needed for land cover differentiation. Each scene covers a width ranging from 13 to 18 kilometers and the length is based on the project's needs. The level of processing needed for analysis (atmospheric and terrain correction) is variable.

While both sets of data offer imagery that is suitable for the land cover analysis, there are pros and cons to each set of imagery. The main advantage of the Landsat data is the combination of complete spatial coverage across Afghanistan, the availability of imagery extending back to 2013, a 16-day revisit time for each location, and the spectral bands needed to classify different land cover types. However, the 30-meter resolution of the data means that an individual pixel may cross multiple land cover types (e.g., crossing adjacent fields). In these cases, the pixel value would represent the average of land cover types (e.g., a pixel crossing the boundary between a field of poppy and an adjacent fallow field) and is therefore harder to classify correctly. Thus, this "mixed pixel" value is harder to classify than a pixel that covers a single land cover type.

² While data are available for Landsat 7 and Landsat 8 satellites, the Landsat 7 data were not suitable for this analysis due to a sensor failure that resulted in swaths of missing data throughout each image.

The main advantage of using Digital Globe data is the availability of multispectral imagery at extremely high resolutions. The small cell size increases the likelihood that a single pixel will cover a single land cover type rather than spanning multiple cover types (Figure 2).

Figure 2. Comparison of Resolution between High- and Moderate-Resolution Imagery



Left: false-color infrared imagery from high-resolution imagery from Digital Globe (2-meter cell size). Right: false-color infrared moderate resolution imagery from Landsat 8 (30-meter cell size). Sources: GeoEye-1, 2017, Digital Globe, Inc., 2018; Landsat 8 OLI, 2017, USGS, 2018.

Additionally, the resolution is high enough that the imagery can identify textural patterns that can be used to differentiate between crop types (e.g., wheat fields are often more homogenous than poppy fields). However, the imagery available from Digital Globe is limited to the spatial and temporal requirements of the projects for which the data were collected. Therefore, the imagery the ET was able to identify was very spotty. While some of this limitation can be offset by the sample and extrapolation techniques noted earlier, a combination of factors made this approach not feasible, including:

- The small number of ground reference samples were limited to the RADP-North region;
- The imagery coincident with the sample data in space and time was difficult to obtain or not available;
- The number of samples available was not enough to be statistically significant;
- Easily obtainable imagery was limited to natural color bands and thus less suitable for discrimination of crop types;

- The amount of individual scenes needed for coverage across all four regions was beyond the resources available; and
- The atmospheric calibration and topographic corrections needed were beyond the resources available.

3.3 NDVI INDEX AND SEASON

Due to limitations in the availability of high-resolution imagery and existing reference samples, as well as the inability to collect new reference samples due to security concerns, the ET relied on the Landsat-based approach noted above. In this approach, the ET relied upon a combination of the NDVI and seasonal differences in crop management to differentiate between land cover types—an approach used by other researchers (Sader, 1990; Curran et al., 2013; Simms, 2016; USAID, 2016; UNODC, 2017). This multi-temporal approach takes advantage of the difference between pre- and post-harvesting schedules to differentiate between poppy and non-poppy fields. Poppy fields are often plowed after harvest, while other crops such as wheat are not (Sader, 1990; UNODC, 2017). In addition, the ET used NDVI values derived from the literature to help differentiate between poppy and non-poppy crops. NDVI is a measure of the amount of chlorophyll content in vegetation. The NDVI value takes advantage of the difference in surface reflectance between the near-infrared and red spectral bands. Equation 1 shows the NDVI calculation:

Equation 1. NDVI calculation

$NDVI = (NIR - Red) / (NIR + Red)$
Where: NDVI = Normalized Difference Vegetation Index; NIR = Near-infrared spectral band – Landsat 8, band 5 (0.851–0.879 μm); and Red = Red spectral band – Landsat 8, band 4 (0.636–0.673 μm).

Fields with vigorous growth (growing season) will have a high NDVI, while less-vigorous or fallow fields (post-harvest) will have a low or zero NDVI (UNODC, 2017). The UNODC 2017 report also noted that it is key to utilize imagery coincident with the flowering stage to the maximum degree possible to allow for better differentiation from other crops, although the flowering stage only lasts for a few weeks and getting cloud-free imagery that coincides with that period can be challenging.

To differentiate between poppy and non-poppy crops, the ET used NDVI values relative to the season—flowering stage or post-harvest stage. The ET used crop calendars specific to each region that were based on the UNODC 2017 report, which are shown in Table 5.

Table 5. Crop Calendar Used to Guide Imagery Dates Needed to Differentiate between Poppy and Non-Poppy Crops (UNODC, 2017)

Region	Project Period	Season	
		Growing/Flowering	Harvest
North	Pre-Implementation	May 2013	July 2013
	Evaluation Period	May 2017	July 2017
South	Pre-Implementation	March/April 2013	June 2013
	Evaluation Period	March/April 2017	June 2017
West	Pre-Implementation	March/April 2014	June 2014
	Evaluation Period	March/April 2017	June 2017

Region	Project Period	Season	
		Growing/Flowering	Harvest
East	Pre-Implementation	March/April 2015	May/June 2015
	Evaluation Period	March/April 2018	May/June 2018

Many of the published NDVI values for poppy vs. other crops are derived from high-resolution imagery and thus represent a more homogenous signal than what would be expected from the moderate-resolution Landsat imagery, which in some cases represents a mixed pixel of different fields or land use types (e.g., poppy, non-poppy crops, and barren). To address this issue, the ET used a range of NDVI values derived from Simms (2016) for both the flowering and post-harvest phase of poppy. Simms (2016) generated spectral profiles of NDVI values from 250-meter MODIS satellite data for different mixes of poppy and non-poppy land cover types for three years and plotted the mixed-pixel values against time (Figure 3).

Figure 3 shows peak NDVI values in 2006 (which was a mix of crop types but had the greatest amount of poppy of the three years reported): about 0.55 in late March and a slightly higher value (about 0.6) in 2005, which had a higher mix of wheat. This is similar to values in the UNODC 2017 study that showed an approximately 0.6 value for poppy and a 0.7 value for wheat in mid-March. Again, the UNODC values were derived from high-resolution imagery. However, during the flowering phase of poppy (early/mid-April), Figure 3 shows NDVI values of about 0.4–0.5 in Helmand Province. The ET compared these values to the NDVI values and those in the Landsat data for a scene covering an agricultural area in the Southern region and found the maximum NDVI value of about 0.49. Taking into account pixels that would represent different mixes of poppy and non-poppy crops, the ET chose an NDVI range of 0.30–0.45 for the flowering season—the lower value capturing pixels with a fairly vigorous vegetative growth and the higher value not exceeding what one might expect for a pure poppy field during the flowering phase (e.g., a value > 0.45 might indicate a majority of wheat). For the harvest period, the ET used a range of NDVI values from 0 to 0.135 for captured fields where the majority of land cover was either fallow (plowed) or had scarce vegetation. Table 6 shows the NDVI values used in the ET’s classification scheme for different land cover types, noting that it is the difference in NDVI bins between seasons (and therefore harvest practices) that differentiates poppy from either other agriculture or other land cover types. Therefore, to be classified as poppy, the NDVI value for a pixel must fall between 0.3 and 0.45 in the flowering season and must be between 0 and 0.135 in the harvest season as poppy is plowed following harvest while other crops such as wheat are not.

Table 6. NDVI Value Ranges Used for Classification

Land Cover Type	Flowering Season NDVI Range (Bin Value)	Harvest Season NDVI Range (Bin Value)
Other agricultural	> 0.45 (1)	> 0.135 (2)
Poppy	0.3–0.45 (1)	0–0.135 (1)
Other land (non-agricultural vegetation, barren, urban, etc.)	0.0 – < 0.3 (0)	
Water/snow/ice	< 0.0 (-1)	< 0.0 (-1)

Figure 3. NDVI Profiles for Three Years Representing Mixed-Pixel Values from Different Combinations of Crop Types within a 250-Meter Pixel from the MODIS Satellite

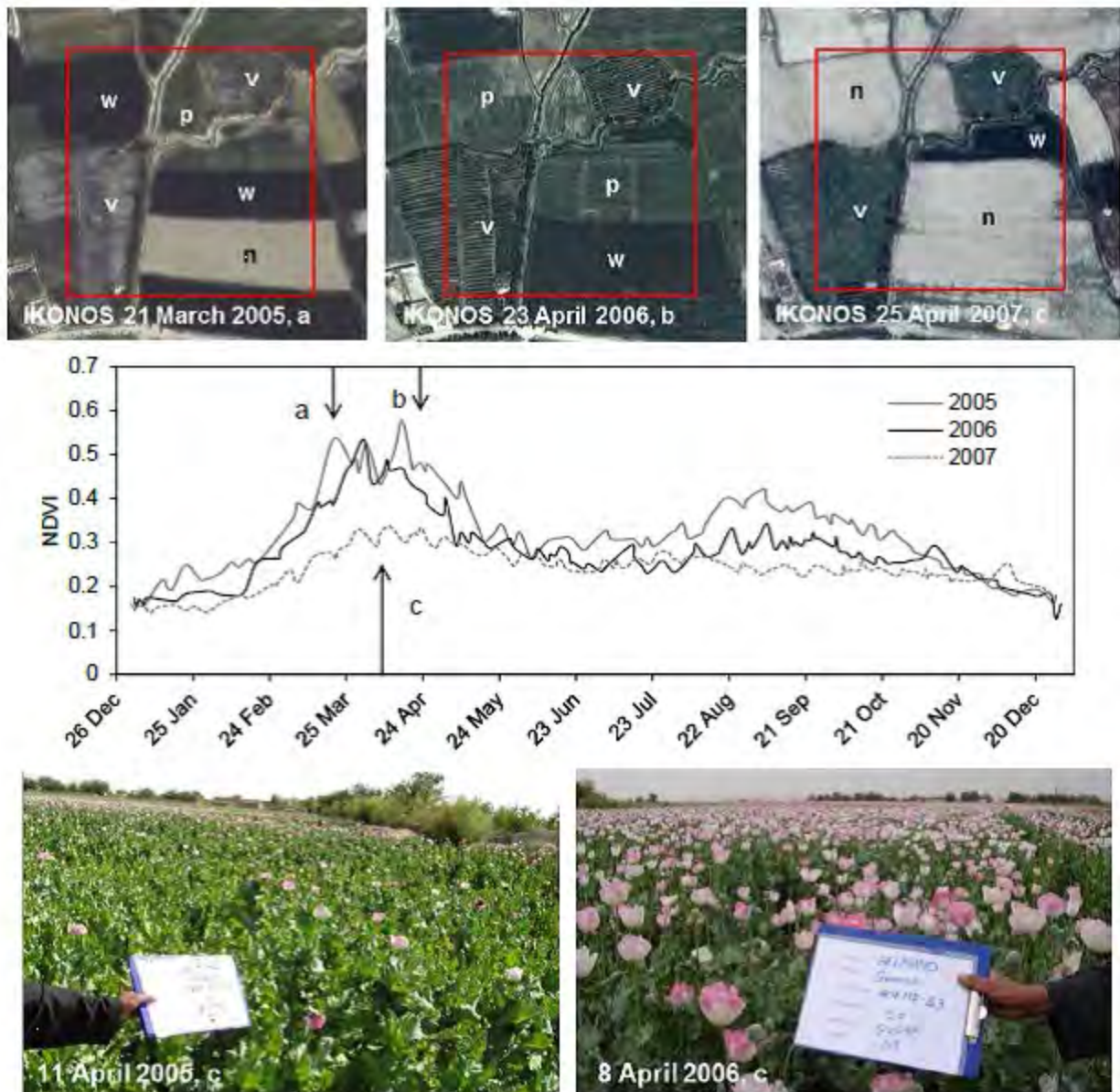


Figure 3.5. Visual comparison of crop-mix interpreted from VHR IKONOS imagery, ground photography and MODIS NDVI profiles for a location in southern Helmand. Crop types (w - wheat; p - opium poppy; n - no-crop; and v - vines) are identified on the true-colour composite IKONOS subsets within the nominal MODIS pixel (red square). The image and photography dates are marked on the profile (a - 3rd week of March; b - 2nd week of April; and c - 3rd week of April). Photography ©UNODC/Ministry of Counter Narcotics, Government of Afghanistan.

Source: Simms, 2016, Figure 3.5, p. 30. (Note: the top-right Ikonos image was originally incorrectly labeled as "IKONOS 25 April 2007, b," but was corrected to read as "IKONOS 25 April 2007, c.")

Although the date of flowering or harvest differed by region, the ET used these same NDVI values for classification across all scenes and regions. While ordinarily the ET would adjust the NDVI values used based on the specific environmental conditions within a scene (or sub-scene), without access to field-verified sample data or information, the ET did not feel comfortable adjusting the criteria. Additionally, the ET's approach maintained the consistency needed across the programmatic periods to increase the likelihood that changes between periods resulted from program implementation rather than differences in relative NDVI values used. The ET also notes that the degree that pixels fall within a single field or span multiple fields also depends on field size, which can vary substantially between regions and even within regions. Lastly, the ET notes that in the vast majority of imagery it was possible to align the imagery date with the crop calendar date needed (the middle of the flowering season or the beginning of the harvest season), but it was not always possible due to cloud cover or poor image quality. A full list of the Landsat 8 scenes used is provided in Annex I.

3.4 DATA AND PROCESSING

As noted above, the ET downloaded Landsat 8 OLI multispectral (11-band) imagery covering the full extent of the RADP programmatic regions. The province/district GIS boundary data were obtained from the ESRI³ ArcGIS hub portal (ESRI, 2018a) and linked to programmatic province and district attribute data provided by USAID implementing partners. The ET downloaded imagery data from two USGS portals: the Landsatlook website (<https://landsatlook.usgs.gov/>) and the USGS Earth Explorer website (<https://earthexplorer.usgs.gov/>). The imagery is 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 is thus suitable for analytic purposes. The ET also queried the imagery for the amount of cloud cover and overall image quality, and downloaded scenes aligned to the year and season shown in the crop calendar by region (Figure 4). In many cases, multiple dates for a single scene for the respective season were available. In these cases, the ET utilized the best imagery based on the following criteria:

- The image fell close to the middle of the flowering season or in the first two weeks of the harvest season;
- The image was cloud-free over the areas of interest;
- The image covered the full extent of the scene boundary (in some cases scenes were clipped); and
- The image date was as consistent as possible with other scenes in the season and region, and across program years to maximize consistency.

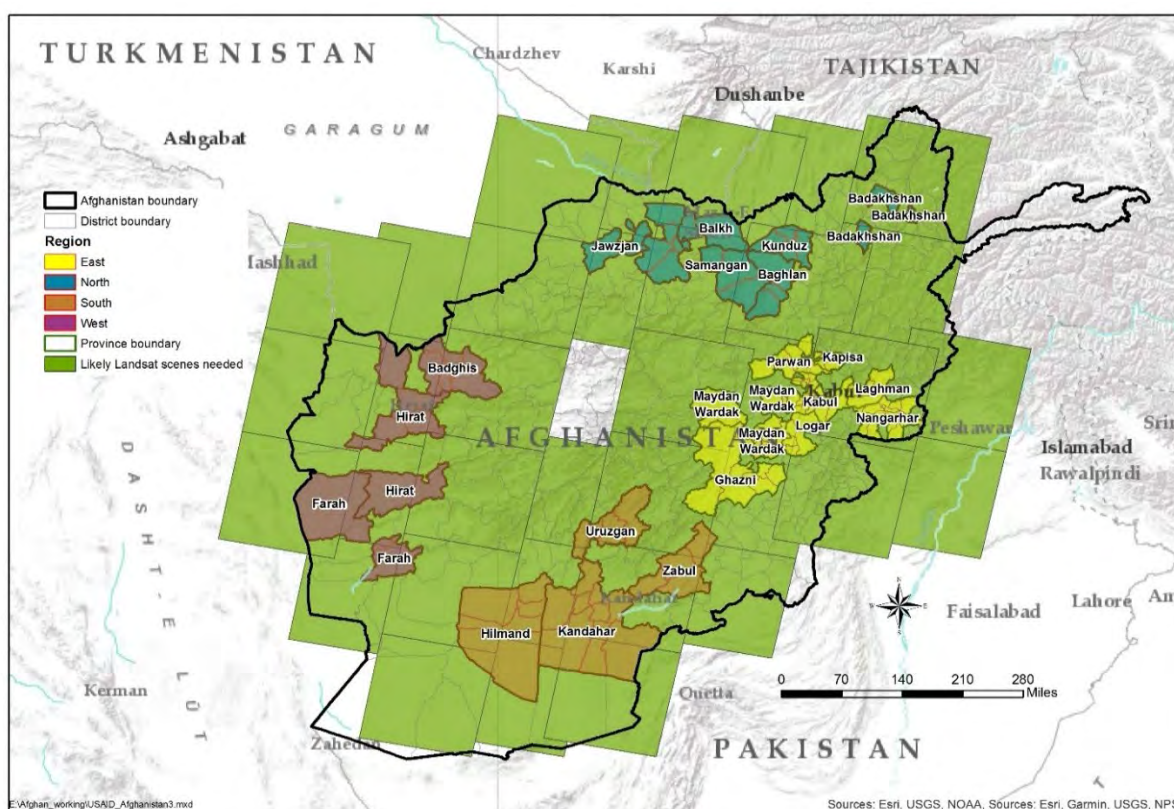
Figure 4 shows the spatial footprints of the individual Landsat 8 scenes needed.

For each image footprint shown on the map, the ET obtained imagery for four images—corresponding to the two seasons (flowering and harvest) and two time periods (pre-program and program interim evaluation). The ET examined each scene downloaded using a false-color infrared band combination (near infrared/red/green) to highlight the vegetative growth and evaluated relative to the criteria above. Taking into account some scenes that extended slightly beyond their boundary, the ET ultimately relied upon 141 scenes (see Annex I).

The ET then converted the imagery into NDVI raster layers using *Equation 1* shown above and then reclassified the NDVI output layers using the classes indicated in Table 6. Figure 5 shows an example of false-color infrared and NDVI imagery for a portion of the RADP-South region.

³ ESRI is an international supplier of GIS software, web GIS, and geodatabase management applications. <https://www.esri.com/en-us/home>.

Figure 4. Spatial Extent of Landsat 8 Scenes Needed across the RADP Regions



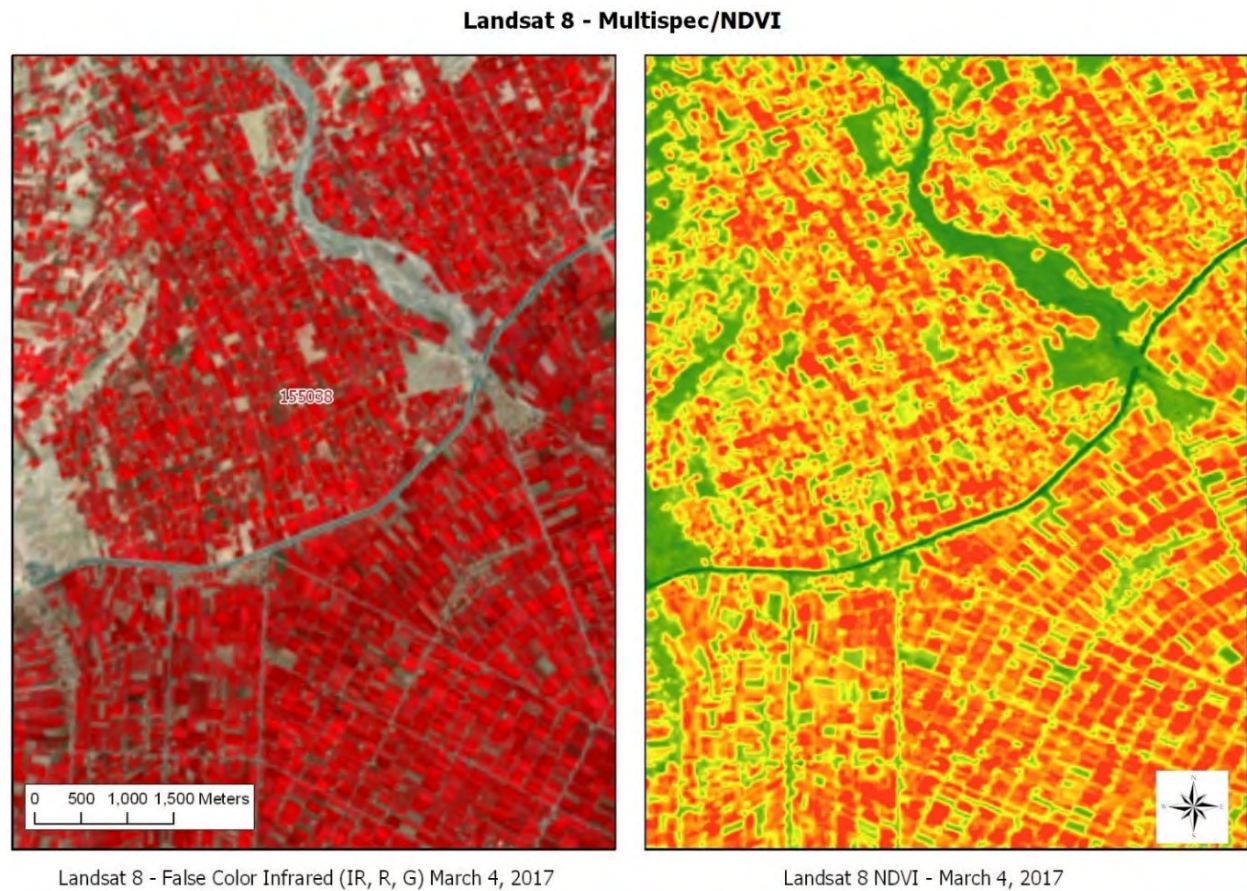
The ET then overlaid the resulting flowering and harvest layers within a GIS and masked the output to limit the analysis area to the programmatic districts within each RADP region (i.e., excluding the area outside of the programmatic districts). Finally, the ET compared the attribute table of final overlay to classify pixels into a final land cover type using the combination of flowering and harvest NDVI class values, as shown in Table 7.

Table 7. Flowering and Harvest Season Criteria Used to Determine Final Land Cover Classification

Flowering Season NDVI Bin	Harvest Season NDVI Bin	Final Land Cover
0, 1 (barren or sparse vegetation)	-1 (water/snow)	"Water/snow" ^a
-1 (water/snow)	0, 1, 2 (barren, sparse, vigorous vegetation)	"Water/snow" ^a
0 (barren or sparse vegetation)	1 (barren or sparse vegetation)	"Other"
0 (barren or sparse vegetation)	2 (vigorous vegetation)	"Other crop"
1 (moderate vegetative growth)	1 (barren or sparse vegetation)	"Likely poppy"
1 (moderate vegetative growth)	2 (vigorous vegetation)	"Other crop"
2 (vigorous vegetation)	1 (barren or sparse vegetation)	"Other crop"
2 (vigorous vegetation)	2 (vigorous vegetation)	"Other crop"

^a Denoted as "water/snow" as it contained water in either season but could indicate a marsh in cases where it was water in one season and had no or some vegetation in the other season.

Figure 5. Portion of the RADP-South Region Showing Landsat 8 Imagery Used in the Classification Process

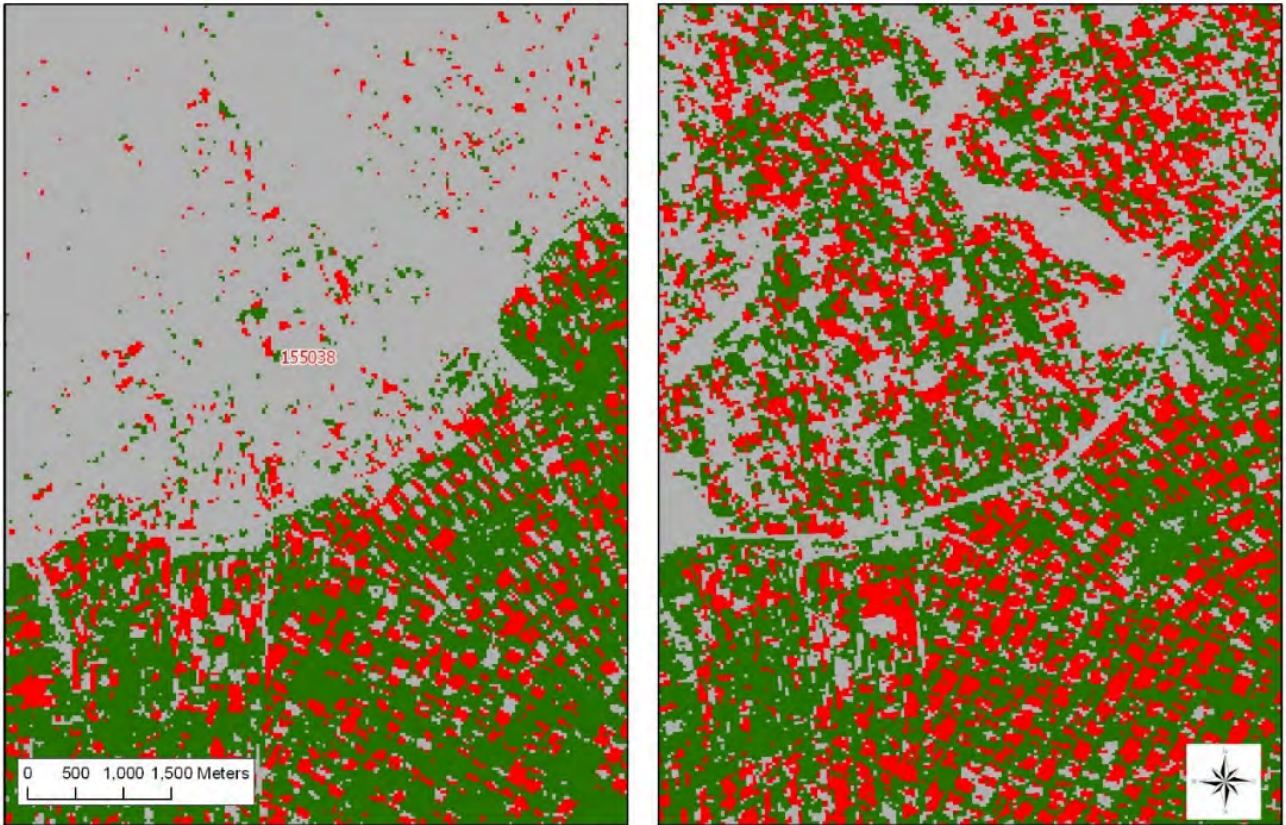


Left: false-color infrared imagery (bands 5, 4, and 3). Right: NDVI layer.

Figure 6 shows an example of output from the classification process for a partial Landsat scene in the RADP-South region. The left side of the figure shows the licit and illicit classification for the pre-program period and the right side shows the output for the evaluation period. The ET conducted all analysis using ArcGIS Pro (v. 2.0 and 2.2.2) software for all image and GIS processing (ESRI, 2018b).

Following the final classification of land cover type, the ET combined the final layer with the district layer and calculated the total area by land cover type by summing the cell count in each final classification within each district. This workflow was conducted for both the pre-program and program interim-evaluation periods and tabulated to compare the change in land cover types.

Figure 6. Example of Final Classification Output for a Partial Scene in the RADP-South Region



Left: pre-program (2013). Right: evaluation period (2017). Red = “likely poppy,” green = “other crop,” gray = “other” (non-vegetated or sparsely vegetated), and light blue = “water/snow.”

4.0 RESULTS AND DISCUSSION

4.1 TABLES OF RESULTS AND DISCUSSION

The results of the ET's analysis are shown in Tables 8–11.

4.1.1 RADP-South Region

For the districts participating in the program in the RADP-South region (Table 8), the ET estimated that just over 23,600 hectares were under poppy in the pre-program period (2013), which rose to 28,401 hectares in the program evaluation period (2017), an increase of about 20 percent. For other agricultural lands, the ET estimated a similar increase: from about 284,000 hectares to about 353,500 hectares, a roughly 24 percent increase in area. However, the area of poppy as a percentage of total agriculture decreased slightly from approximately 7.7 percent in 2013 to 7.4 percent in 2017. It is interesting to note that the amount of water/snow was estimated to be approximately 120 percent higher in 2017 than 2013. Therefore, it could be that the increase in the area under poppy cultivation was due to increased water availability. This argument is supported by the fact that the area under other crops increased as well. The reduction in area under poppy as a percentage of total area under agriculture is encouraging though.

Table 8. Change in Area under Poppy and Other Uses across the RADP-South Region

Classification	Hectares		Change			
	2013	2017	Change in Hectares	% Change in Hectares	Poppy as % of Total Agriculture	
					2013	2017
Poppy	23,663	28,401	4,738	+20.0%	7.7%	7.4%
Other agriculture	284,285	353,499	69,214	+24.3%	N/A	
Water/snow/ice	9,155	20,201	11,046	+120.7%	N/A	

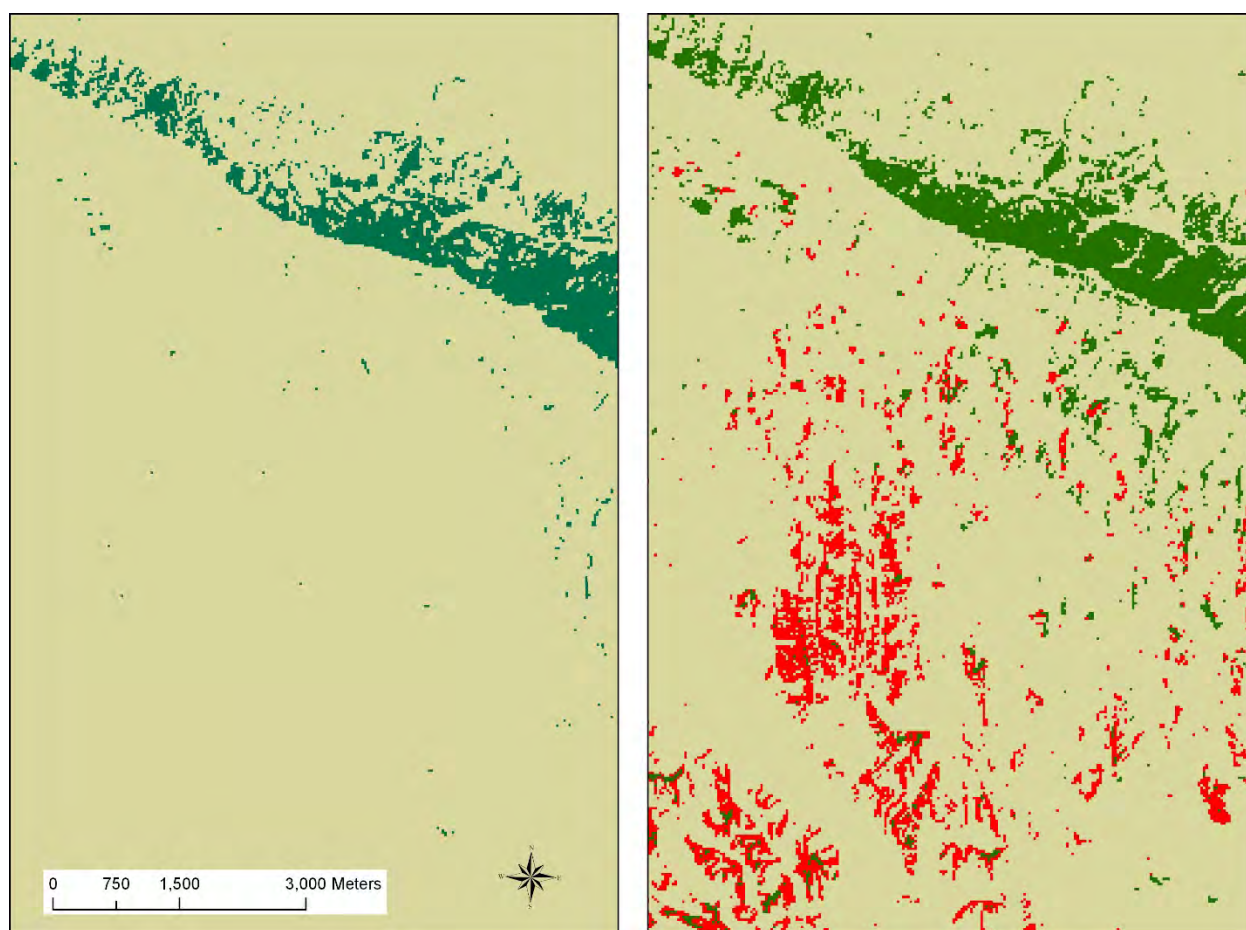
4.1.2 RADP-North Region

In the RADP-North region (Table 9), the ET estimated a dramatic increase in poppy production between the two periods. In 2013, the ET estimated there were about 15,000 hectares of poppy, which increased to almost 81,000 hectares by 2017, an increase of approximately 440 percent. In contrast, in the RADP-North region, the area under other agriculture decreased about 22 percent, from about 700,000 hectares in 2013 to about 548,000 hectares in 2017. The ET also saw an increase of about 67 percent in land cover classified as water/snow. Therefore, the increase could be due to increased water availability. However, the ET saw areas of poppy production in the desert areas in the evaluation period but not in the pre-program period (Figures 7–9), implying that the increase could be due to a shift from licit to illicit agriculture—especially as the decrease in absolute amount of other agriculture (151,673 hectares) was roughly twice as much as the increase in poppy area (65,827 hectares). Figure 7 shows the desert area in the pre-program and evaluation periods, highlighting the expansion of poppy crop. Figure 8 shows the same area of poppy cultivation (left) and natural color high-resolution imagery (right). The ET's initial thought was that the evaluation period classification was in error. However, a large-scale (zoomed in) portion of the same area (Figure 9) clearly shows agricultural fields, which gave the ET confidence in their classification as poppy.

Table 9. Change in Area under Poppy and Other Uses across the RADP-North Region

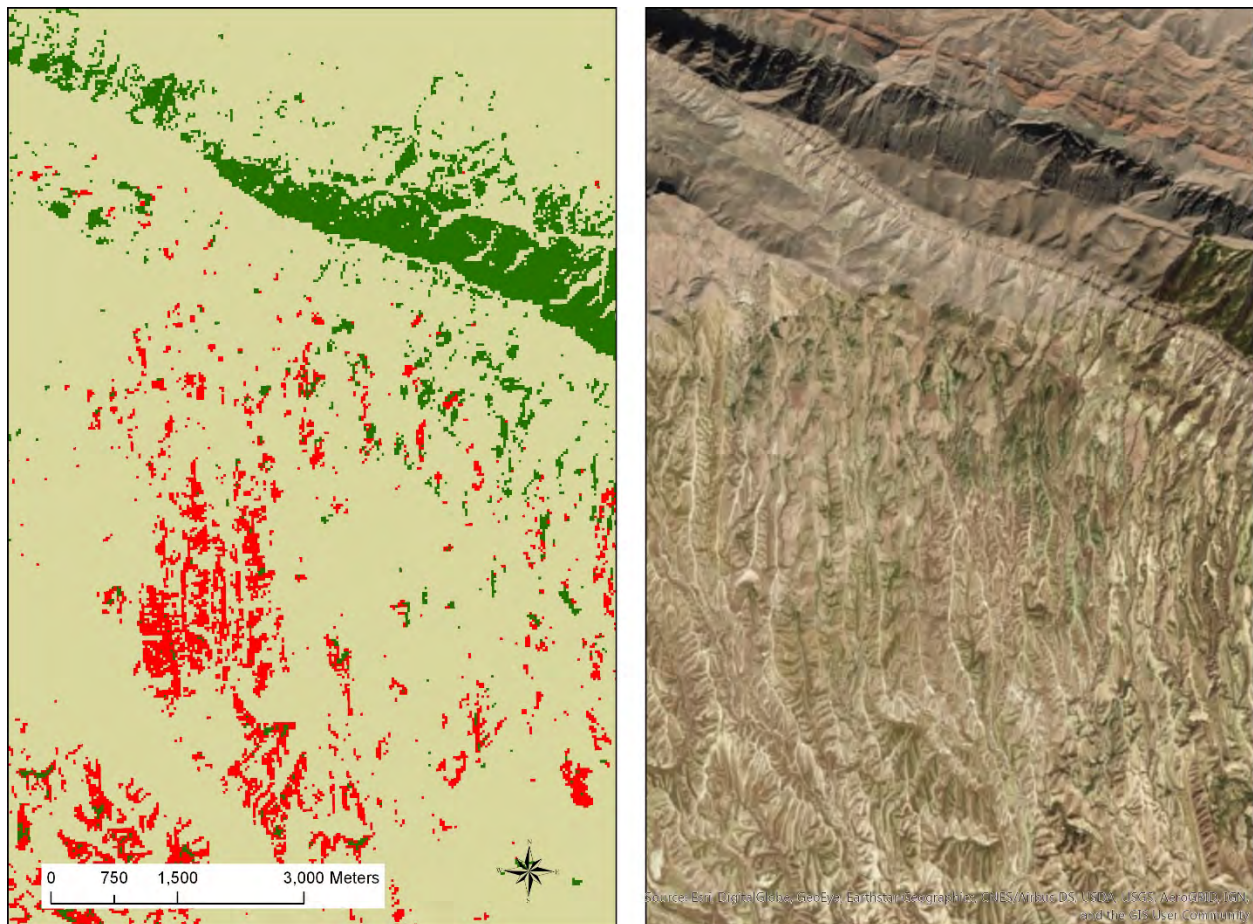
Classification	Hectares		Change			
	2013	2017	Change in Hectares	% Change in Hectares	Poppy as % of Total Agriculture	
					2013	2017
Poppy	14,967	80,794	65,827	+439.8%	2.1%	12.9%
Other agriculture	699,315	547,642	(151,673)	-21.7%	N/A	
Water/snow/ice	9,909	16,581	6,672	+67.3%	N/A	

Figure 7. Desert Area in the RADP-North Region Showing Expansion of Poppy Crop



Left: pre-program period. Right: evaluation period. Red = poppy, green = other agriculture, and beige = other land cover (e.g., desert).

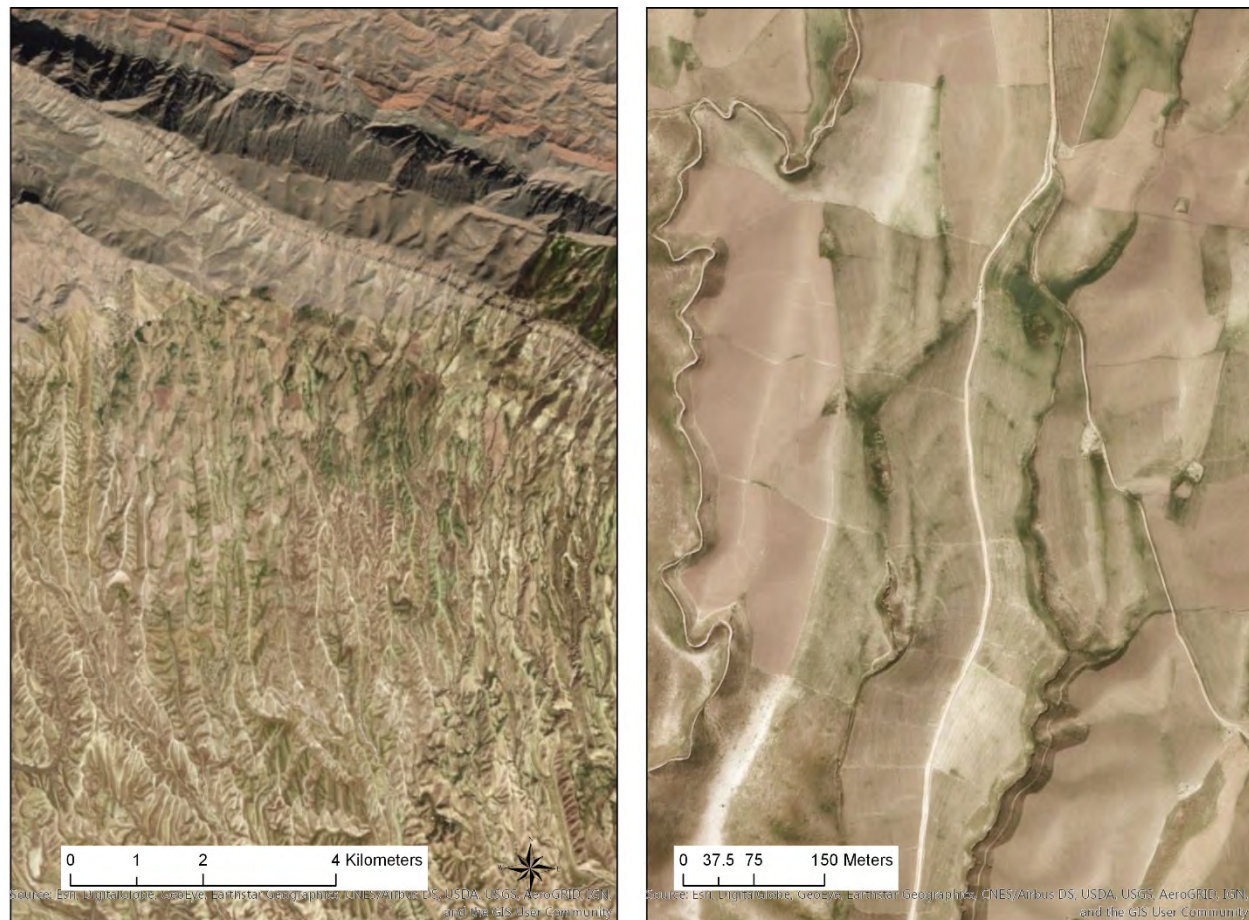
Figure 8. Images of the RADP-North Region for the Evaluation Period (2018) Showing Expansion of Poppy Production into the Desert



Left: evaluation period (2018) in the RADP-North region showing expansion of poppy production into the desert. Red = poppy, green = other crop, beige = other land cover (e.g., desert). Right: high-resolution natural color imagery of same area shown on left. Imagery source: ESRI, 2018c.

Mansfield (2018) found a similar expansion of poppy into desert regions in the RADP-South region in response to eradication efforts. Mansfield also noted that as the cost of production is high in these desert areas due to the need to pump water for irrigation, any agricultural production would necessarily be a high-value crop such as poppy. As a percentage of total agriculture, poppy production increased from 2.1 percent in 2013 to almost 13 percent by 2017. Alternatively, it could be that the low amount of production in 2013 was due to environmental conditions—such as a cold spring.

Figure 9. Images of Desert Region of Poppy Expansion in the RADP-North Region to Highlight Potential Agricultural Fields



4.1.3 RADP-East Region

In the RADP-East region (Table 10), there was a large decrease in poppy production between the post-program (2018) and pre-program (2015) periods. The ET estimated that there were about 12,000 hectares in 2015, which decreased to approximately 2,600 hectares in 2018; the reduction of about 9,400 hectares represented a decrease in crop area of about 78 percent. The ET saw a large decrease in other agricultural production between the evaluation and pre-program periods as well, with over 1 million hectares estimated in 2015 and about 786,000 hectares in 2018, a reduction of about 23 percent. As a percentage of total agriculture, poppy represented a very small amount, but decreased from 1.1 percent to 0.3 percent between the time periods. Similar to the RADP-North and RADP-South regions, the ET saw an increase in land cover classified as water/snow—with a doubling (202 percent) of area between the two periods. There are a number of potential reasons for the large reduction in illicit crop production between the program periods. However, given that other agriculture decreased by about 240,000 hectares and the fact that there was over a 200 percent increase in water (mainly in the form of snow) in 2018 compared to 2015, the idea that environmental conditions could have been less favorable for agriculture in the latter time period is supported.

Table 10. Change in Area under Poppy and Other Uses across the RADP-East Region

Classification	Hectares		Change			
	2015	2018	Change in Hectares	% Change in Hectares	Poppy as % of Total Agriculture	
					2015	2018
Poppy	11,873	2,593	(9,280)	-78.2%	1.1%	0.3%
Other agriculture	1,026,206	785,874	(240,331)	-23.4%	N/A	
Water/snow/ice	164,726	496,768	332,043	+201.6%	N/A	

4.1.4 RADP-West Region

Lastly, the RADP-West region (Table 11) saw a large reduction in area under poppy cultivation between the 2014 pre-program period and the 2017 program evaluation period. In 2014, the ET estimated approximately 31,500 hectares of poppy, while in 2017 the ET's estimate was approximately 13,500 hectares, a decrease of about 57 percent. Other agricultural areas increased by approximately 150 percent, from over 257,000 hectares in 2014 to more than 640,000 hectares in 2017. The percentage of poppy to total agriculture also dropped from about 11 percent to 2 percent between the time periods. This, along with the fact that total licit agriculture increased by about 383,000 hectares, could plausibly be explained as a shift from illicit to licit crops, although other environmental factors could be at play. This is supported by the increase in area classified as snow/water (about 3,600 hectares) between the time periods that could have made conditions more favorable for licit agriculture. Similar to the RADP-North region, the ET saw areas in the non-traditional agricultural areas (e.g., desert) that met the criteria for poppy cultivation (Figure 10). However, these same areas were not classified as poppy in the evaluation period, which is one reason for the reduction in overall poppy area.

Table 11. Change in Area under Poppy and Other Uses across the RADP-West Region

Classification	Hectares		Change			
	2014	2017	Change in Hectares	% Change in Hectares	Poppy as % of Total Agriculture	
					2014	2017
Poppy	31,518	13,490	(18,028)	-57.2%	10.9%	2.1%
Other agriculture	257,369	640,210	382,841	148.8%	N/A	
Water/snow/ice	1,660	5,284	3,624	+218.4%	N/A	

Figure 10. Images of the RADP-West Region for the Evaluation Period (2018) Showing Expansion of Poppy Production into the Desert



Left: evaluation period (2018) in the RADP-West region showing poppy production into the desert. Red = poppy, green = other vegetation, beige = other land cover (e.g., unvegetated). Right: high-resolution natural color imagery of same area shown on left.

Imagery source: ESRI, 2018c.

4.2 DISCUSSION

The differences the ET found between time periods are undoubtedly the result of a variety of limitations to the data and approach, as well as other factors that may have affected changes in crop production. In terms of limitations, the ET faced a number of issues that may have led to misclassification of poppy vs. other types of agriculture. The limitations to the ET's analysis included things that might cause differences between the crop calendar used and on-the-ground conditions, such as crop management practices (e.g., when poppies are planted or harvested, whether the field is plowed after harvest, and whether fields are intercropped or not); climatic anomalies (e.g., colder spring, hotter summer, drought, or higher snowpack that would result in changes timing of flowering or harvest); and variation in crop calendars between latitudes and elevation. As Simms (2016) noted, there was a two-month difference in the timing of flowering between adjacent valleys in the same province due to differences in valley elevations. In addition, there were other limitations such as the quality of imagery (including cloud cover, haze, etc.), dates of the imagery available, the inability to customize thresholds to every variation of mixed-pixel values resulting from different underlying land cover types (due to field sizes, intercropping, and vegetative health), and the sparsity of ground reference samples aligned with different phenologic stages for the specific programmatic years.

As noted in Section 3, Methods, without better information on any of the above issues, the ET chose to use a classification approach that relied on spectral ranges gleaned by other research and applied the method consistently across time periods to minimize the impact of subjective changes by the analyst.

Ultimately, the thresholds the ET used to classify areas of poppy cultivation assume that the crops are flowering on the first-dated imagery and have been harvested on the second-dated imagery. As the flowering period lasts approximately two weeks, if the image used was not aligned with the flowering period, the ET would most likely not classify the crop as poppy, which would result in an underestimation of poppy area. Additionally, as described in Section 3, Methods, the NDVI values used were based partially on estimates from the MODIS (250-meter resolution) mixed-pixel analysis conducted by Simms (2016). While the ET did adjust the specific values to account for the difference in pixel size (Landsat 30-meter resolution) and the effect of different thresholds on the amount of poppy classified, the ET sensitivity analysis was based on a limited agricultural region in the RADP-South region. The ET emphasizes that even minor changes in the NDVI thresholds used (both in flowering and post-harvest periods) can have a substantial impact on what is classified as poppy or other crop type. In the end, the ET believes that the ranges used in this analysis are conservative.

To account for the regional and topographic influences that affect the timing of flowering and harvesting, it could be possible to adjust the crop calendar both regionally and locally by incorporating gridded data of monthly temperature and precipitation anomalies (difference from the average) or the elevation of agricultural fields into the analysis. This would help guide the choice of image dates to use. That said, understanding the relationship between the timing of flowering and harvesting based on these climatic and topographic differences could be challenging without an analog location with similar environmental conditions.

In addition to the technical limitations, other factors were likely to have caused actual changes in the area of poppy cultivation. For instance, the onset of disease or outbreak of pests (or avoidance of such) could also affect the amount of poppy cultivation either directly or indirectly—directly by reducing cultivated area outright or indirectly by increasing the cultivated area as a result of the adoption of herbicides or pesticides. The latter effect is supported by other research. According to the Afghanistan Research and Evaluation Unit Issues Paper (Mansfield, 2018), the use of herbicides in Southwest Afghanistan in 2013 was limited but by 2017 herbicides were almost universal.

In addition to the environmental issues that may have affected the ET's classification results, a number of socioeconomic factors are likely to have affected the changes found. These include:

- Economic factors that influence both the cost of production and/or market value of poppy vs. other crops;
- Civil unrest; and
- Eradication efforts (including foreign military intervention).

This last bullet has resulted in expansion into desert lands away from traditional agricultural areas. It is likely that this is what the ET saw in the RADP-North region and potentially the RADP-West region, although it is difficult to be certain without ground reference or ancillary data. However, Mansfield (2018) reported a large expansion into desert lands since 2013, due to a combination of the eradication efforts in conjunction with technological innovation in the RADP-South region, including:

- Deep wells for irrigation (made possible due to price of poppy);
- Reduction in well costs due to solar expansion (80 percent increase in reservoirs and pump stations between 2016 and 2017); and
- Use of herbicides.

Similarly, the UNODC 2017 report noted that the use of solar panels, fertilizers, and pesticides may have increased the profitability of poppy cultivation even in less-favorable environmental conditions.

It is difficult to compare the ET's findings with those of the UNODC 2017 report for a number of reasons. First, the ET notes that the years in common between the two studies are limited somewhat by region. While the RADP-North, -South, and -West regions have results from both pre-program and evaluation period years, the evaluation period for the RADP-East region was for the year 2018—which has yet to be evaluated by UNODC. As noted by Simms (2016) and others, there is a high variability in poppy cultivation between years, so without having estimates for the exact same years, a direct comparison is hard to support.

Second, at the province level, the ET's estimates include only those districts that participated in the program and thus represents a small subset of a province (see Figure 1), while the estimates from the UNODC report are for the entire province area.

A third difference is that the UNODC 2017 analysis reported only areas of poppy cultivation of at least 100 hectares, whereas the results of this analysis include all areas.

Lastly, the UNODC 2017 report provides a central estimate of poppy area as well as the upper and lower bounds of the 95 percent confidence interval at the province level. As the spread between the upper and lower bounds can be up to 6.7 times different and represents the entirety of the province, it makes province comparison between the studies difficult.

However, with these caveats, the ET compared the changes for the UNODC 2017 report (2016–2017 change) and their changes between the pre-program and evaluation periods. The UNODC 2017 report found a substantial increase in poppy cultivation for all regions, while the ET found a mix of increases and decreases in their analysis. In the RADP-South region, UNODC found a 67 percent increase in poppy, while the ET found a 20 percent increase (2013–2017). In the RADP-West region, the UNODC reported a 6 percent increase compared to a 57 percent reduction in this study (2014–2017). In the RADP-East region, the UNODC reported a 36 percent increase in poppy while the ET found a 78 percent reduction (2015–2018). Finally, in the RADP-North region, the UNODC report found an increase of 441 percent, while the ET found a 439 percent increase. Again, the years and total domains differ, but the results were in agreement in the direction of the sign (i.e., positive or negative) in two regions but opposite for the other two. The large reduction in 2018 in the RADP-East region in particular is interesting as it could indicate less-than-ideal climate conditions for poppy (such as a colder-than-average spring) or a decrease in demand.

The ET also notes that the sampling domain used in the UNODC 2017 report did not include lands containing less than 0.25 square kilometers of arable land. This may therefore have excluded areas of new poppy expansion (e.g., desert areas), which could result in an underestimate of the amount of poppy crop estimated.

However, as noted above, the UNODC 2017 report also provides results at the individual district level and includes estimates for the pre-program and implementation years for all but the RADP-East region (for which only the pre-program results from UNODC are available). Tables 12–15 show the results of the district level comparison as well as the summation of the districts within the region.

Comparing the results across districts for the same year shows substantial differences between the estimates—both in terms of absolute numbers and percent change. The likely reason is due to a combination of factors, including the classification methodology and the extent and comprehensiveness of the analysis. However, without having a statistically valid accuracy assessment across all regions, it is difficult to say which is more accurate, especially given the range from the upper and lower bounds (95 percent confidence intervals) noted at the province level in the UNODC 2017 report (Table 16). It is also probable that the accuracy estimates are quite variable at a sub-province level. As noted above, the UNODC 2017 analysis uses a different methodology based on where poppy production has traditionally occurred. In these traditional agricultural areas, the UNODC relies on a statistically based sampling approach, using visual classification of very high-resolution imagery along with ancillary

information (ground reference data) as the basis for the identification of poppy. While the use of high-resolution imagery is undoubtedly superior to moderate-resolution image classification in these areas where attributes such as field texture and hue can be exploited, there will undoubtedly be errors due to misinterpretation of imagery (especially if the image dates are not aligned with the flowering period). These errors would then be reflected in the ratios used in the UNODC estimates.

Additionally, while the UNODC 2017 assessment utilizes a high number of well-distributed samples, there are likely areas where the relationships they used would not apply. The ET's analysis showed a high degree of variation between different agricultural areas—with some areas showing the salt-and-pepper pattern (e.g., Figure 6), while other areas were relatively homogenous and devoid of poppy. While these latter areas could be the result of misinterpretation based on differences between the crop calendar dates and on-the-ground timing of flowering/harvest, other areas are likely classified correctly, with little poppy production. In these cases, estimates based on the ratios from other areas would be incorrectly applied.

As noted above, in areas with a low level of poppy production, the UNODC 2017 analysis used a targeted approach using full coverage of satellite imagery for portions of the province that were identified as likely to have poppy cultivation (based on a surveillance system and information by village “headmen”). In areas with no indication of poppy cultivation, they used a village survey approach without any image analysis. In both of these cases, the ET feels that the UNODC is likely missing many outlying areas of poppy cultivation. In using a comprehensive set of imagery across all the study areas, the ET found that some districts that the UNODC found devoid of poppy cultivation had substantial poppy cultivation in the ET's estimates. These seem to occur in outlying areas of deserts where poppy cultivation has expanded (Figures 7–10). In these cases, it could be that the UNODC methodology missed areas that were not either sampled or targeted as they did not conduct a wall-to-wall estimation. It could also be that the ET's approach misclassified the image as poppy. However, a number of factors support the ET's assessment: 1) these are areas of vigorous vegetative growth that match the seasonal management associated with poppy (Figure 10); 2) the higher cost of production (irrigation) means that any crops grown are likely to be of high value, which further supports that they are poppy; and 3) high-resolution imagery of the region shows agricultural activity (Figures 7–10).

Table 12. RADP-West Region, District-Level Comparison between UNODC 2017 Report and Pre-Program Period

Region	Province	District	Poppy (hectares) UNODC (2014)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2014–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
West	Badghis	Ab Kamari	0	281	1,906	112	NA	-94%
West	Badghis	Muqur	47	2,097	992	374	4,362%	-62%
West	Badghis	Qadis	57	1,802	12,217	4,924	3,061%	-60%
West	Badghis	Qala-I-Naw	49	38	750	3	-22%	-100%
West	Farah	Anar Dara	104	1	155	189	-99%	22%
West	Farah	Farah	4,760	47	1,700	1,883	-99%	11%
West	Farah	Pusht Rod	2,214	1,499	1,790	2,225	-32%	24%
West	Hirat	Guzara	0	0	1,409	171	NA	-88%
West	Hirat	Injil	0	0	402	74	NA	-82%
West	Hirat	Karukh	0	0	1,295	253	NA	-80%

Region	Province	District	Poppy (hectares) UNODC (2014)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2014–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
West	Hirat	Koshk	0	575	2,116	531	NA	-75%
West	Hirat	Pashtun Zarghun	0	0	1,923	364	NA	-81%
West	Hirat	Shindand	729	517	4,863	2,389	-29%	-51%
Total			7,960	6,857	31,518	13,490	-14%	-57%

Note: Totals may not sum due to rounding.

Table 13. RADP-South Region, District-Level Comparison between UNODC 2017 Report and Pre-Program Period

Region	Province	District	Poppy (hectares) UNODC (2013)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2013–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
South	Hilmand	Garmser	4,527	13,211	5,813.1	205.29	192%	-96%
South	Hilmand	Lashkar Gah	1,828	4,669	1,486.8	616.14	155%	-59%
South	Hilmand	Nad Ali	19,136	27,398	4,709.16	14,028.84	43%	198%
South	Hilmand	Nahri Sarraj	18,701	18,464	5,983.47	7,384.14	-1%	23%
South	Hilmand	Nawa-l-Barak Zayi	97	4,064	1,382.13	1,958.04	4,090%	42%
South	Kandahar	Arghandab	18	1,183	22.86	21.6	6,472%	-6%
South	Kandahar	Daman	0	157	204.84	27	NA	-87%
South	Kandahar	Kandahar	46	113	180.99	65.43	146%	-64%
South	Kandahar	Khakrez	1,006	416	17.19	23.58	-59%	37%
South	Kandahar	Maywand	16,382	9,284	1,131.57	876.15	-43%	-23%
South	Kandahar	Panjwayi	984	2,141	600.3	28.62	118%	-95%
South	Kandahar	Spin Boldak	207	1,880	392.31	616.5	808%	57%
South	Kandahar	Zhari	7,017	7,605	828	151.74	8%	-82%
South	Uruzgan	Chora	611	1,263	27.18	15.75	107%	-42%
South	Uruzgan	Dihrawud	3,321	5,648	294.57	1,210.77	70%	311%
South	Uruzgan	Tirin Kot	1,936	8,368	341.01	1,126.71	332%	230%
South	Zabul	Qalat	28	10	90.99	13.5	-64%	-85%
South	Zabul	Shahjoy	96	0	15.75	1.71	-100%	-89%
South	Zabul	Shinkay	0	0	107.64	24.21	NA	-78%
South	Zabul	Tarnak Wa Jaldak	0	959	32.85	5.13	NA	-84%

Region	Province	District	Poppy (hectares) UNODC (2013)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2013–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
Total			75,941	106,833	23,663	28,401	41%	20%

Table 14. RADP-North Region, District-Level Comparison between UNODC 2017 Report and Pre-Program Period

Region	Province	District	Poppy (hectares) UNODC (2013)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2013–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
North	Badakhshan	Baharak	322	0	110.43	103.68	-100%	-6%
North	Badakhshan	Fayzabad	48	10	1,002.78	515.88	-79%	-49%
North	Badakhshan	Kishim	141	1,128	2,170.8	3,312.45	700%	53%
North	Badakhshan	Yaftal Sufla	18	52	647.91	751.05	189%	16%
North	Baghlan	Baghlani Jadid	0	0	680.4	10,415.79	NA	1431%
North	Baghlan	Dahana-I-Ghuri	0	0	1,676.07	7,784.73	NA	364%
North	Baghlan	Puli Khumri	0	0	62.82	482.04	NA	667%
North	Balkh	Balkh	0	2,334	416.52	1,434.15	NA	244%
North	Balkh	Chimtal	400	5,768	150.57	4,418.91	1342%	2835%
North	Balkh	Dawlatabad	0	1	658.17	4,170.96	NA	534%
North	Balkh	Dihdadi	0	6	16.11	1,540.44	NA	9462%
North	Balkh	Khulm	0	0	2,016.27	3,664.53	NA	82%
North	Balkh	Mazari Sharif	0	0	0.09	0.63	NA	600%
North	Balkh	Nahri Shahi	0	0	144.9	3,438.09	NA	2273%
North	Balkh	Sholgara	0	0	159.93	12,877.47	NA	7952%
North	Jawzjan	Aqcha	0	20	0.54	31.14	NA	5667%
North	Jawzjan	Fayzabad	0	396	11.34	320.31	NA	2725%
North	Jawzjan	Shibirghan	0	867	5.04	2,669.76	NA	52871%
North	Kunduz	Aliabad	0	0	20.88	1,427.94	NA	6739%
North	Kunduz	Chahar Dara	0	0	1,759.41	2,150.55	NA	22%
North	Kunduz	Khanabad	0	0	2,056.86	13,258.44	NA	545%
North	Kunduz	Kunduz	0	0	582.93	2,076.66	NA	256%
North	Samangan	Aybak	0	0	184.59	1,225.62	NA	564%
North	Samangan	Feroz Nakhchir	0	0	4.5	708.12	NA	15636%
North	Samangan	Hazrati Sultan	0	0	55.17	982.17	NA	1680%
North	Samangan	Khuram Wa Sarbagh	0	0	371.7	1,024.11	NA	176%

Region	Province	District	Poppy (hectares) UNODC (2013)	Poppy (hectares) UNODC (2017)	Likely Poppy (hectares) (2013–Pre-Program)	Likely Poppy (hectares) (2017–Post-Program)	UNODC Change	RADP Change
Total			929	10,582	14,967	80,786	1039%	440%

Table 15. RADP-East Region, District-Level Comparison between UNODC 2017 Report and Pre-Program Period

Region	Province	District	Poppy (hectares) UNODC (2015)	Poppy (hectares) UNODC (2017)*	Likely Poppy (hectares) (2015–Pre-Program)	Likely Poppy (hectares) (2018–Post-Program)	UNODC Change	RADP Change
East	Ghazni	Andar	0	0	0.81	0.09	NA	-89%
East	Ghazni	Bahrami Shahid (Jaghata)	0	0	10.35	0	NA	-100%
East	Ghazni	Dih Yak	0	0	10.71	0.09	NA	-99%
East	Ghazni	Ghazni	0	0	26.46	0.09	NA	-100%
East	Ghazni	Jaghuri	0	0	30.96	0.36	NA	-99%
East	Ghazni	Nawur	0	0	7.56	0	NA	-100%
East	Ghazni	Qarabagh	0	0	41.22	0.18	NA	-100%
East	Ghazni	Waghaz	0	0	3.96	0	NA	-100%
East	Kabul	Bagrami	0	0	19.26	0.36	NA	-98%
East	Kabul	Chahar Asyab	0	0	0.45	0	NA	-100%
East	Kabul	Dih Sabz	0	0	14.76	0.27	NA	-98%
East	Kabul	Farza	0	0	0	0	NA	NA
East	Kabul	Guldara	0	0	0	0	NA	NA
East	Kabul	Kabul	0	0	3.6	0	NA	-100%
East	Kabul	Kalakan	0	0	3.33	0	NA	-100%
East	Kabul	Khaki Jabbar	0	0	0.18	0	NA	-100%
East	Kabul	Mir Bacha Kot	0	0	0.27	0	NA	-100%
East	Kabul	Musayi	0	0	8.1	1.17	NA	-86%
East	Kabul	Paghman	0	0	0.18	0.09	NA	-50%
East	Kabul	Qarabagh	0	0	18.09	0.18	NA	-99%
East	Kabul	Surobi	321	435	186.93	16.92	36%	-91%
East	Kapisa	Hisa-i-Awali Kohistan	0	0	62.37	0.36	NA	-99%
East	Kapisa	Koh Band	10	29	8.1	0	190%	-100%
East	Kapisa	Mahmudi Raqi	0	0	38.52	7.02	NA	-82%

Region	Province	District	Poppy (hectares) UNODC (2015)	Poppy (hectares) UNODC (2017)*	Likely Poppy (hectares) (2015–Pre- Program)	Likely Poppy (hectares) (2018–Post- Program)	UNODC Change	RADP Change
East	Kapisa	Nijrab	21	57	2.43	0	171%	-100%
East	Laghman	Alingar	277	575	575.37	88.83	108%	-85%
East	Laghman	Mihtarlam	123	281	1,218.42	146.25	128%	-88%
East	Laghman	Qarghayi	4	137	598.05	135.54	3325%	-77%
East	Logar	Baraki Barak	0	0	14.49	41.76	NA	188%
East	Logar	Charkh	0	0	2.16	3.15	NA	46%
East	Logar	Mohammad Agha	0	0	5.31	1.35	NA	-75%
East	Logar	Puli Alam	0	0	4.77	1.26	NA	-74%
East	Nangarhar	Acheen	1,090	1,364	634.23	46.35	25%	-93%
East	Nangarhar	Bati Kot	4	757	855.63	448.11	18825%	-48%
East	Nangarhar	Bihsud	0	0	302.85	52.74	NA	-83%
East	Nangarhar	Chaparhar	1,504	2,337	805.05	78.66	55%	-90%
East	Nangarhar	Goshta	6	0	542.61	13.68	-100%	-97%
East	Nangarhar	Jalalabad	0	0	5.67	0.72	NA	-87%
East	Nangarhar	Kama	0	0	463.32	426.69	NA	-8%
East	Nangarhar	Khogayani	2,996	4,728	1,736.01	246.69	58%	-86%
East	Nangarhar	Kot	872	49	590.67	113.85	-94%	-81%
East	Nangarhar	Muhmand Dara	19	505	342.9	31.86	2558%	-91%
East	Nangarhar	Pachier Agam	1,066	1,231	191.16	47.25	15%	-75%
East	Nangarhar	Rodat	389	1,802	1,079.82	222.57	363%	-79%
East	Nangarhar	Shinwar	70	1,245	833.04	53.1	1679%	-94%
East	Nangarhar	Surkh Rod	188	816	208.44	346.59	334%	66%
East	Parwan	Bagram	0	0	341.46	6.21	NA	-98%
East	Parwan	Chaharikar	0	0	9.72	2.97	NA	-69%
East	Parwan	Salang	0	0	0.09	0	NA	-100%
East	Parwan	Sayd Khel	0	0	6.93	5.58	NA	-19%
East	Parwan	Shekh Ali	0	0	0	0	NA	NA
East	Parwan	Shinwari	0	0	1.44	0.54	NA	-63%
East	Parwan	Sia Gird (Ghorbund)	0	0	0.09	0	NA	-100%
East	Maydan Wardak	Chaki Wardak	0	0	0.81	0.09	NA	-89%

Region	Province	District	Poppy (hectares) UNODC (2015)	Poppy (hectares) UNODC (2017)*	Likely Poppy (hectares) (2015–Pre-Program)	Likely Poppy (hectares) (2018–Post-Program)	UNODC Change	RADP Change
East	Maydan Wardak	Jaghathu	0	0	0.09	0	NA	-100%
East	Maydan Wardak	Jalrez	0	0	0	0	NA	NA
East	Maydan Wardak	Maydan Shahr	0	0	0	0	NA	NA
East	Maydan Wardak	Markazi Bihsud	0	0	0.09	0	NA	-100%
East	Maydan Wardak	Saydabad	0	0	4.14	3.51	NA	-15%
Total			8,960	16,348	11,873	2,593	82%	-78%

Table 16. Province-Level Summaries of Poppy Cultivation, Showing Upper and Lower 95% Confidence Ranges

Province	Point Estimate (hectares)	Lower Bound (hectares)	Upper Bound (hectares)
Badakhshan	8,311	3,215	13,406
Badghis	24,723	11,518	37,928
Day-Kundi	1,508	605	2,412
Farah	12,846	7,210	18,482
Fayrab	22,797	15,171	30,422
Ghor	4,228	1,949	6,507
Helmand	144,018	129,371	158,664
Jawzjan	3,236	1,778	4,695
Kandahar	28,010	18,967	37,052
Kunar	1,634.91	741	2,528
Laghman	2,257	591	3,924
Nangarhar	18,976	13,154	24,799
Nimroz	11,466	7,314	15,619
Uruzgan	21,541	13,297	29,785
Zabul	2,131	527	3,735
Target provinces	20,620	-	-
National	328,304	301,472	355,135
Rounded	328,000	301,000	355,000

Source: UNODC, 2017, Table 26, p. 54.

In summary, given the differences in methodologies and uncertainties in classification techniques, especially with the number of environmental, economic, and social variables that may affect the classification results, it is not surprising that the ET estimates may differ (sometimes substantially) from the results that others have found. However, as noted above, many of the environmental uncertainties could be reduced by incorporating climate and topography GIS data into the analysis. These results would undoubtedly allow the ET to better align the imagery with crop phenology and thereby improve estimates of poppy and non-poppy crops. Additionally, by combining these enhancements and running the classification on both programmatic and non-programmatic districts, the ET may be better able to understand the impact of the program.

Having said this, in the ET's final assessment, the team believes that using high-resolution imagery, along with statistical sampling, is superior to classifying poppy crop than using an NDVI threshold approach—at least in the agricultural area traditionally associated with poppy cultivation. However, the sampling and targeted approaches used by UNODC may miss areas that could be captured from the Landsat approach used here. It may therefore be useful to augment the UNODC's sample/target approach to include the Landsat/NDVI-based analysis used by the ET to identify areas of poppy cultivation in outlying regions.

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ANNEX

ANNEX I: LANDSAT SCENES USED IN ANALYSIS

Region	Collection	Data Type	Path/Row	Acquisition Date	Year	Month	Day	Period	Season
East	LC08	LITP	151036	20180412	2018	04	12	Post-Program	Flowering
East	LC08	LITP	152036	20180403	2018	04	03	Post-Program	Flowering
East	LC08	LITP	153035	20180325	2018	03	25	Post-Program	Flowering
East	LC08	LITP	153036	20180325	2018	03	25	Post-Program	Flowering
East	LC08	LITP	153037	20180325	2018	03	25	Post-Program	Flowering
East	LC08	LITP	154036	20180401	2018	04	01	Post-Program	Flowering
East	LC08	LITP	154037	20180401	2018	04	01	Post-Program	Flowering
East	LC08	LITP	151036	20180530	2018	05	30	Post-Program	Harvesting
East	LC08	LITP	152036	20180606	2018	06	06	Post-Program	Harvesting
East	LC08	LITP	153035	20180613	2018	06	13	Post-Program	Harvesting
East	LC08	LITP	153036	20180613	2018	06	13	Post-Program	Harvesting
East	LC08	LITP	153037	20180613	2018	06	13	Post-Program	Harvesting
East	LC08	LITP	154036	20180604	2018	06	04	Post-Program	Harvesting
East	LC08	LITP	154037	20180620	2018	06	20	Post-Program	Harvesting
East	LC08	LITP	151036	20150404	2015	04	04	Pre-Program	Flowering
East	LC08	LITP	152036	20150427	2015	04	27	Pre-Program	Flowering
East	LC08	LITP	153035	20150504	2015	05	04	Pre-Program	Flowering
East	LC08	LITP	153036	20150504	2015	05	04	Pre-Program	Flowering
East	LC08	LITP	153037	20150504	2015	05	04	Pre-Program	Flowering
East	LC08	LITP	154036	20150409	2015	04	09	Pre-Program	Flowering
East	LC08	LITP	154037	20150409	2015	04	09	Pre-Program	Flowering
East	LC08	LITP	151036	20150607	2015	06	07	Pre-Program	Harvesting
East	LC08	LITP	152036	20150614	2015	06	14	Pre-Program	Harvesting
East	LC08	LITP	153035	20150605	2015	06	05	Pre-Program	Harvesting
East	LC08	LITP	153036	20150605	2015	06	05	Pre-Program	Harvesting
East	LC08	LITP	153037	20150605	2015	06	05	Pre-Program	Harvesting
East	LC08	LITP	154036	20150612	2015	06	12	Pre-Program	Harvesting
East	LC08	LITP	154037	20150612	2015	06	12	Pre-Program	Harvesting
West	LC08	LITP	156036	20170412	2017	04	12	Post-Program	Flowering
West	LC08	LITP	156037	20170412	2017	04	12	Post-Program	Flowering
West	LC08	LITP	157035	20170419	2017	04	19	Post-Program	Flowering
West	LC08	LITP	157036	20170419	2017	04	19	Post-Program	Flowering
West	LC08	LITP	157037	20170403	2017	04	03	Post-Program	Flowering

Region	Collection	Data Type	Path/Row	Acquisition Date	Year	Month	Day	Period	Season
West	LC08	LITP	I57038	20170419	2017	04	19	Post-Program	Flowering
West	LC08	LITP	I58037	20170309	2017	03	09	Post-Program	Flowering
West	LC08	LITP	I56036	20170615	2017	06	15	Post-Program	Harvesting
West	LC08	LITP	I57035	20170606	2017	06	06	Post-Program	Harvesting
West	LC08	LITP	I57036	20170606	2017	06	06	Post-Program	Harvesting
West	LC08	LITP	I57037	20170606	2017	06	06	Post-Program	Harvesting
West	LC08	LITP	I57038	20170606	2017	06	06	Post-Program	Harvesting
West	LC08	LITP	I58037	20170613	2017	06	13	Post-Program	Harvesting
West	LC08	LITP	I56036	20140420	2014	04	20	Pre-Program	Flowering
West	LC08	LITP	I56037	20140319	2014	03	19	Pre-Program	Flowering
West	LC08	LITP	I57035	20140427	2014	04	27	Pre-Program	Flowering
West	LC08	LITP	I57036	20140427	2014	04	27	Pre-Program	Flowering
West	LC08	LITP	I57037	20140427	2014	04	27	Pre-Program	Flowering
West	LC08	LITP	I57038	20140427	2014	04	27	Pre-Program	Flowering
West	LC08	LITP	I58037	20140418	2014	04	18	Pre-Program	Flowering
West	LC08	LITP	I56036	20140623	2014	06	23	Pre-Program	Harvesting
West	LC08	LITP	I57035	20140630	2014	06	30	Pre-Program	Harvesting
West	LC08	LITP	I57036	20140630	2014	06	30	Pre-Program	Harvesting
West	LC08	LITP	I57037	20140630	2014	06	30	Pre-Program	Harvesting
West	LC08	LITP	I57038	20140630	2014	06	30	Pre-Program	Harvesting
West	LC08	LITP	I58037	20140621	2014	06	21	Pre-Program	Harvesting
North	LC08	LITP	I52034	20170502	2017	05	02	Post-Program	Flowering
North	LC08	LITP	I52035	20170518	2017	05	18	Post-Program	Flowering
North	LC08	LITP	I53034	20170509	2017	05	09	Post-Program	Flowering
North	LC08	LITP	I53035	20170509	2017	05	09	Post-Program	Flowering
North	LC08	LITP	I54034	20170516	2017	05	16	Post-Program	Flowering
North	LC08	LITP	I54035	20170516	2017	05	16	Post-Program	Flowering
North	LC08	LITP	I55034	20170523	2017	05	23	Post-Program	Flowering
North	LC08	LITP	I55035	20170507	2017	05	07	Post-Program	Flowering
North	LC08	LITP	I52034	20170721	2017	07	21	Post-Program	Harvesting
North	LC08	LITP	I52035	20170721	2017	07	21	Post-Program	Harvesting
North	LC08	LITP	I53034	20170712	2017	07	12	Post-Program	Harvesting
North	LC08	LITP	I53035	20170712	2017	07	12	Post-Program	Harvesting
North	LC08	LITP	I54034	20170719	2017	07	19	Post-Program	Harvesting

Region	Collection	Data Type	Path/Row	Acquisition Date	Year	Month	Day	Period	Season
North	LC08	LITP	I54035	20170719	2017	07	19	Post-Program	Harvesting
North	LC08	LITP	I55034	20170710	2017	07	10	Post-Program	Harvesting
North	LC08	LITP	I55035	20170710	2017	07	10	Post-Program	Harvesting
North	LC08	LITP	I52034	20130523	2013	05	23	Pre-Program	Flowering
North	LC08	LITP	I52035	20130523	2013	05	23	Pre-Program	Flowering
North	LC08	LITP	I53034	20130514	2013	05	14	Pre-Program	Flowering
North	LC08	LITP	I53035	20130530	2013	05	30	Pre-Program	Flowering
North	LC08	LITP	I54034	20130505	2013	05	05	Pre-Program	Flowering
North	LC08	LITP	I54035	20130521	2013	05	21	Pre-Program	Flowering
North	LC08	LITP	I55034	20130613	2013	06	13	Pre-Program	Flowering
North	LC08	LITP	I55035	20130528	2013	05	28	Pre-Program	Flowering
North	LC08	LITP	I52034	20130726	2013	07	26	Pre-Program	Harvesting
North	LC08	LITP	I53034	20130717	2013	07	17	Pre-Program	Harvesting
North	LC08	LITP	I53035	20130717	2013	07	17	Pre-Program	Harvesting
North	LC08	LITP	I54034	20130708	2013	07	08	Pre-Program	Harvesting
North	LC08	LITP	I54035	20130708	2013	07	08	Pre-Program	Harvesting
North	LC08	LITP	I55034	20130715	2013	07	15	Pre-Program	Harvesting
North	LC08	LITP	I55035	20130715	2013	07	15	Pre-Program	Harvesting
South	LC08	LITP	I53037	20170407	2017	04	07	Post-Program	Flowering
South	LC08	LITP	I53038	20170407	2017	04	07	Post-Program	Flowering
South	LC08	LITP	I54037	20170414	2017	04	14	Post-Program	Flowering
South	LC08	LITP	I54038	20170414	2017	04	14	Post-Program	Flowering
South	LC08	LITP	I54039	20170414	2017	04	14	Post-Program	Flowering
South	LC08	LITP	I55037	20170421	2017	04	21	Post-Program	Flowering
South	LC08	LITP	I55038	20170304	2017	03	04	Post-Program	Flowering
South	LC08	LITP	I55039	20170507	2017	05	07	Post-Program	Flowering
South	LC08	LITP	I56038	20170412	2017	04	12	Post-Program	Flowering
South	LC08	LITP	I56039	20170412	2017	04	12	Post-Program	Flowering
South	LC08	LITP	I53037	20170610	2017	06	10	Post-Program	Harvesting
South	LC08	LITP	I53038	20170610	2017	06	10	Post-Program	Harvesting
South	LC08	LITP	I54037	20170601	2017	06	01	Post-Program	Harvesting
South	LC08	LITP	I54038	20170601	2017	06	01	Post-Program	Harvesting
South	LC08	LITP	I54039	20170601	2017	06	01	Post-Program	Harvesting
South	LC08	LITP	I55037	20170608	2017	06	08	Post-Program	Harvesting

Region	Collection	Data Type	Path/Row	Acquisition Date	Year	Month	Day	Period	Season
South	LC08	LITP	I55038	20170608	2017	06	08	Post-Program	Harvesting
South	LC08	LITP	I55039	20170608	2017	06	08	Post-Program	Harvesting
South	LC08	LITP	I56038	20170615	2017	06	15	Post-Program	Harvesting
South	LC08	LITP	I56039	20170615	2017	06	15	Post-Program	Harvesting
South	LC08	LITP	I55038	20130426	2013	04	26	Pre-Program	Flowering
South	LC08	LITP	I53037	20130428	2013	04	28	Pre-Program	Flowering
South	LC08	LITP	I53038	20130428	2013	04	28	Pre-Program	Flowering
South	LC08	LITP	I54037	20130505	2013	05	05	Pre-Program	Flowering
South	LC08	LITP	I54038	20130419	2013	04	19	Pre-Program	Flowering
South	LC08	LITP	I54039	20130419	2013	04	19	Pre-Program	Flowering
South	LC08	LITP	I55037	20130426	2013	04	26	Pre-Program	Flowering
South	LC08	LITP	I55039	20130426	2013	04	26	Pre-Program	Flowering
South	LC08	LITP	I56038	20130417	2013	04	17	Pre-Program	Flowering
South	LC08	LITP	I56039	20130410	2013	04	10	Pre-Program	Flowering
South	LC08	LITP	I53037	20130615	2013	06	15	Pre-Program	Harvesting
South	LC08	LITP	I53038	20130615	2013	06	15	Pre-Program	Harvesting
South	LC08	LITP	I54037	20130606	2013	06	06	Pre-Program	Harvesting
South	LC08	LITP	I54038	20130606	2013	06	06	Pre-Program	Harvesting
South	LC08	LITP	I54039	20130606	2013	06	06	Pre-Program	Harvesting
South	LC08	LITP	I55037	20130613	2013	06	13	Pre-Program	Harvesting
South	LC08	LITP	I55038	20130613	2013	06	13	Pre-Program	Harvesting
South	LC08	LITP	I55039	20130613	2013	06	13	Pre-Program	Harvesting
South	LC08	LITP	I56038	20130604	2013	06	04	Pre-Program	Harvesting
South	LC08	LITP	I56039	20130604	2013	06	04	Pre-Program	Harvesting