Remote Sensing for Humanitarian Practitioners

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INTRODUCTION

Over the past decade, the humanitarian space has witnessed an exponential increase in the implementation of technology in response, monitoring, and research. The use of satellite imagery, in particular, has gained prominence in this space. Although used for decades prior as a means of remotely gathering intelligence of military activity, the early 21st century has since seen a steady increase in the use of this data in humanitarian response, including for monitoring mobile populations and vulnerable communities in conflict and disaster.

However, while satellite imagery is gaining prominence in the humanitarian sector, the data is still largely underused. The lack of knowledge of what is presented within the data and the trepidation of approaching analysis without formal training inhibits the full utilization of imagery. The benefits of providing imagery analysis are widely recognized across many fields, but this technology has yet to be mainstreamed within the humanitarian community. Satellite imagery allows for analysis to be conducted remotely, which is critical for elevating the situational awareness of humanitarian operators on the ground in complex emergencies as well as their corresponding headquarters. Analytical satellite and geospatial data can provide critical insights into the conditions of areas that are not readily available to these operators, at a scope not detectable by individuals on the ground.

Since 2016, WFP's Vulnerability Analysis and Mapping (VAM) has collaborated with the Signal Program on Human Security & Technology at the Harvard Humanitarian Initiative (HHI) in an effort to conduct food and human security analysis on displaced populations in conflict areas. Combining VAM's agricultural-based analysis in affected areas along with the conflict-based satellite imagery analysis conducted at HHI for the past several years, the project resulted in the monitoring and analysis of over 60 individual displaced population camps and settlements, documenting structure increase and decrease, damaged dwellings from conflict, population movements, flooding, burned agriculture, and other phenomena affected by both conflict and natural disasters in the areas in consideration.

In this guide you will find practical examples and materials based on the analysis and methodologies developed and implemented during the course of the project. A wide range of countries were analyzed, including South Sudan and Uganda, from which this guide will draw examples. The example locations in this guide will include Pajok in South Sudan and Palorinya Refugee Settlement in Uganda. These examples will primarily be used to demonstrate structure identification and counting techniques. Beyond this region, examples will be drawn from Dikwa, Nigeria to exemplify damaged civilian dwellings and the effects of flooding. As you will learn, familiarizing yourself with the location of analysis and its context, is crucial for successful analysis. In the appendices of this guide you will find additional materials to help you further your understanding of the discussed work. This will include definitions of terms underlined throughout this guide, sources of satellite imagery, tools and relevant literature.

This guide is geared towards educating people with various backgrounds and varying degrees of analytical experience. Whether you're well-versed in imagery analysis, just beginning, or simply want to understand how this technology is implemented in a humanitarian context and the potential benefits to your work, this instructional document provides many of the principal techniques that are the foundation of satellite imagery analysis in humanitarian conflict settings.

SOFTWARE INSTALLATION

Background: Open Source VS. Proprietary Software

The wide-ranging applications and needs associated with data visualization and spatial analysis have contributed to the development of a range of commercial and open source geospatial platforms. Both commercial and open source platforms have benefits and drawbacks that must be considered. The benefits of commercial GIS software include that the interface tends to be user-friendly and the associated companies provide consistent and accessible technical support. Unfortunately, commercial software are often costly and operate on Windows systems only, potentially limiting user accessibility. Some examples of commercial GIS software include ArcGIS, ERDAS Imagine, and Terrset. Of the available proprietary software, ArcGIS remains the industry standard and will be used to demonstrate analysis examples throughout this guide.

Open source software, on the other hand, are easily downloaded and the analysis capabilities are often just as wholistic as their commercial counterparts. Open source software relies on the collaborative efforts of their users, and this broader base of contributors typically means there is increased feedback and more frequent updates. However, open source software has, at times, a less consistent release cycles and the associated documentation often experiences a lagged release. Examples of open source software includes QGIS, Jump GIS, and GRASS GIS. QGIS is a free open source software that may be installed on Mac, Windows, and Linux operating systems and is comparable to ArcGIS in terms of user interface and functionality.

This guide will focus specifically on ArcGIS Pro, which is a part of the ArcGIS suite. Given that the ArcGIS Pro platform is becoming the go-to ESRI platform, this workbook uses ArcGIS Pro tools to characterize and explain spatial analysis. ArcGIS Pro is a relatively new platform and if you have prior access to ArcMap, the ArcGIS Pro methods discussed throughout this guide are replicated for ArcMap in Appendix IV. If you do not have access to a Windows operating system and/or do not have access to the ArcGIS Suite, Appendix IV also includes replicated steps for use in QGIS.

In addition to aforementioned software platforms, Google Earth Pro is an open source software that is recommended for visual analysis. The following sections will outline how to download and install ArcGIS Pro, QGIS, and Google Earth Pro.

Download and Installation: ArcGIS Pro (video)

If you have previously worked with ArcGIS, you most likely used ArcMap to visualize data or conduct spatial analysis. ArcGIS Pro was introduced by ESRI in 2015 and aims to improve data visualization, 2D and 3D analysis, and integration with ArcGIS online.

Download a free 21-day trial version of ArcGIS Pro. Please note that ArcGIS is only compatible on a Windows operating system and you should also make sure that your computer meets the technical requirements for the software download. While the trial download steps are defined below, installation steps are more thoroughly described on the ArcGIS website. Please default to the online steps when unsure.

1. Enter the required information on the download page
2. Activate your online trial subscription via the email you received from ESRI
3. Create a username and password to create an ArcGIS Online account
4. Fill in the information required on the "set up your organization" page, save, and continue
5. When the pop up window appears, asking you to download ArcGIS Pro or Continue with ArcGIS Online, opt to download the software
6. You will be redirected to the a new page where you can specify a preferred language and download ArcGIS Pro
7. As the software downloads, scroll down to the Activate software section of the page and click on the hyperlinked phrase "ArcGIS Online" in step 1

Now you have to configure the ArcGIS Pro License Extensions

8. You will be redirected to your ArcGIS Online profile where you should navigate to Licenses section on the Overview page of your ArcGIS Online profile.
9. Click Manage licenses
10. Near the bottom of the page, choose to configure the licenses
11. You should now be able to check all the extensions and click "assign"

Once the extensions have been configured, it is time to set up ArcGIS Pro.

12. Open the downloaded ArcGIS Pro .exe and navigate through the setup wizard
13. Open ArcGIS Pro and log into your ArcGIS Online to begin using the platform

Before purchasing ArcGIS, please inquire if your organization or academic institution already has an organizational license for the software. If you do not have an organizational license, you may choose to purchase a personal license. ArcGIS desktop has three license levels: Basic, Standard, and Advanced. You can compare the capabilities of all three licensing levels to determine which license is most suitable for your needs. In addition, you must specify if you would like to purchase a one-year or indefinite license, a concurrent or single-use license. The prices greatly vary from license to license. Login to receive price quotations for the varying ArcGIS licensing.

If you wish to purchase a full version of ArcGIS Pro, you must download the ArcGIS desktop suite which includes ArcGIS Pro, ArcMap, ArcCatalog, ArcScene and ArcGlobe.

If you wish to download the software to conduct spatial analysis similar to the steps outlined in this workbook, we recommend that you download at least ArcGIS Standard. If you anticipate using ArcGIS for spatial analysis beyond this workshop, you are welcome to download ArcGIS Advanced, which will give you access to a large array of advanced spatial analysis tools.

Download and Installation: QGIS (video)

Alternatively, you can download QGIS. QGIS is a free open source software that has similar analysis tools as in ArcGIS. Please keep in mind that QGIS is compatible with Mac, Windows, Linux and has a different installation link for each operating system on the website. This guide will only detail the installation process for QGIS on a Windows operating system. Please note that QGIS makes a distinction between a long-term release vs stable release.

1. Under Download for Windows, navigate to QGIS Standalone Installed Version 2.18. Please confirm whether your computer is 64-bit or 32-bit and select the appropriate version to begin the download.
2. Open the .exe file once it's been downloaded. A dialog will appear and ask for permission for the program to make changes to your hard drive. Select "yes" to proceed.
3. Complete the setup wizard to complete the installation process. You may leave the default options selected.
4. When the download is complete, a folder named "QGIS 2.18" and a program named "GRASS GIS 7.4.1" will appear on your desktop. In the QGIS 2.18 folder, select QGIS Desktop 2.18.22 to launch QGIS Las Palmas. Please note that QGIS 2.18 is referred to as Las Palmas while other versions of the software will have different names.

Download and installation: Google Earth Pro (video)

Like QGIS, Google Earth Pro is compatible on Windows, Mac, or Linux operating systems. You can download Google Earth Pro.

1. Once downloaded, launch the setup wizard.
2. A dialog will appear and ask for permission for the program to make changes to your hard drive. Select "yes" to proceed.
3. Once the installation is complete, the software will launch and be ready to use.

DATA ACQUISITION

Selecting Areas of Interest

Prior to downloading imagery, you must first identify your area of interest (AOI) which should capture the feature(s) of interest. While selecting your AOI, you must also define the extent of the area. For example, if your AOI is Palorinya Refugee settlement, will your AOI include the entire settlement? Some of the surrounding area? These are important consideration to make when selecting and defining your AOI. One of the most effective ways to make these decisions is by using Google Earth. Google Earth allows you to visualize your AOI, delineate its boundaries, and export the file as .kml or .kmz into ArcGIS or alternative imagery catalogues.

With Google Earth, you also have the benefit of accessing archival imagery by using the time slider function found in the toolbar. However, it is important to note the limitations: timely imagery in some locations, such as Rukban, Syria (at time of this writing), imagery has not been uploaded for several years and is not representative of conditions closer to the dates of interest.

Lastly, Google Earth is a useful tool in establishing AOI boundaries for commercial imagery acquisition, as a customer can often order very high-resolution commercial satellite imagery by sending a provider a .kml over their AOI of exactly what image they prefer. Do note that typically an imagery provider, such as DigitalGlobe, require a *minimum* area of imagery to be purchased.

AOI Selection in Google Earth (video)

1. Open Google Earth
2. You can travel to a location of an AOI by two different means:
    1. The Search Bar **-** In the vertical side bar on the left-hand side, locate the Search field. Here you can enter place names or coordinates in *decimal degrees* or a general *degree, minutes, seconds* format for a location. Note that map coordinates are listed near the bottom of the map view can be displayed using 5 different formats. You are able to modify those under Tools >> Options >> Show Lat/Long
    2. Upload File **-** In the toolbar select: File >> Open…, then choose your file type (*Google Earth* for .kml or .kmz, *ESRI* for .shp, etc.)
3. Demarcate AOI - select the Polygon function located in the toolbar. Begin to place your points around the perimeter of the AOI. Note that the polygon will be color-filled automatically, which can be adjusted via the

New Polygon menu that opens once the function is selected, under the Style, Color tab.

    1. If you are demarcating an AOI for which you want to request imagery from a commercial provider, ensure that it covers a minimum area of coverage (specified by imagery provider). To measure the area of the AOI, use the Measurements tab in the New Polygon menu.

4. Save, Export **-** Once your polygon is completed, you can title the polygon in the Name field of the New Polygon window.
    1. In the toolbar select File >> Save >> Save Place As
    2. Choose between filetype .kml or .kmz. Both file formats are used to display geospatial data. Kml stands for Keyhole Markup Language, which uses XML notation to store file information. A .kmz file is simply a compressed .kml file

While Google Earth is an interactive tool for visual exploration of the selected AOI and its surrounding areas, additional data products provide further insight on environmental factors in the region, which may be important to consider when conducting analysis. Products such as the Global Surface Water Explorer hold information about the spatial and temporal distribution of surface water. This may be a product of interest when considering drought, agriculture, vegetation health, and population movement. Additional data products concentrate on atmospheric composition, vegetation health, climatic changes etc. Appendix III includes a list of data products that may assist in AOI selection and exploration. Once an AOI is confirmed, appropriate satellite imagery must be identified to ensure high quality analysis.

Google Earth Engine

Google Earth Engine is a powerful cloud computing platform that offers access to petabytes of satellite imagery and geospatial datasets. In addition to being open source, this innovative platform makes it possible to visualize and analyze large volumes of satellite imagery on the fly enabling the analyst to rapidly identify trends, monitor and quantify change over time.

Earth Engine allows you to explore the data in a couple of different ways. The Datasets web page is a catalogue of the main public datasets available on Earth Engine. The Earth Engine Explorer interface allows you to visualize and navigate across the image catalogue in time and location. While these tools are useful for inspecting the data catalogue, metadata and planning for your next analytical project, in truth the full potential of Earth Engine is accessed through the JavaScript code editor. Here, the analyst can visualize, interact with and analyze multiple type on satellite and geospatial datasets.

To access the platform you must first create a gmail account (skipping this step if you have an existing account). After which you can follow the instructions to create a Google Earth Engine account. **Access is not always instant** and it some cases **may take several days** to be granted.

Satellite Imagery: History

Before discussing and comparing current sources of imagery, it is important to understand the origin and evolution of remotely sensed satellite imagery. In 1959, The U.S. Government began the Corona satellite program, with the initial intention of implementing the newly developed remote sensing technology to gather photographic intelligence of Soviet military installments during the Cold War (*fig. 1*). This started the first (for the period) high resolution satellite imagery operation in history.

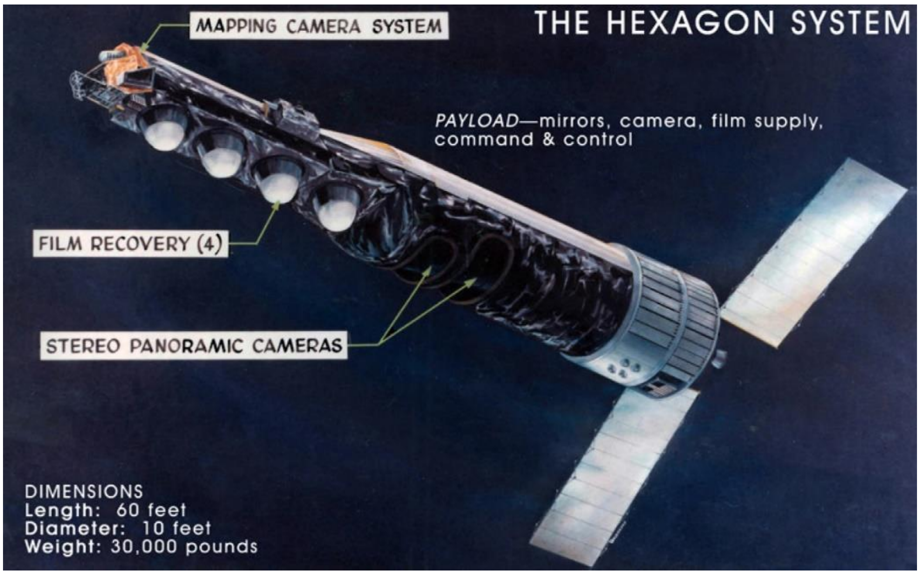


Figure 1. Artist conception of KH-9 HEXAGON satellite, declassified and released by NRO on 17 Sep 2011. Source: Wikipedia.

As one could imagine, the advances in technology have created a vast divide between how this imagery was collected then and now. Our current delivery system is on convenient digital platforms but in its early days the process involved a lot more time, cost, and manual labor.

Like our satellites now, the Corona satellites were launched on a rocket to reach the orbit of space above the earth's surface, undetectable to the human eye from the earth's surface. However, this is where many of the similarities end between the satellites of today and what was used back then.

The Corona satellites were equipped with canisters of 70mm film, and a computer programmed to identify its targets based on decisions made by the Corona Targeting Program. Once the film was completely used up, the canister, which was housed in a capsule, would be ejected from the satellite and begin its descent to the earth's surface. When the capsule reached a certain altitude, parachutes were emitted from the capsule body and the retrieval process begins.

A carefully coordinated flight is initiated, and an airplane with a giant metal ‘claw’ affixed to its tail intended to hook onto the capsule parachute, is sent to retrieve the film (*fig. 2*). When the capsule is collected, which some-times was not the case due to the airplane missing its target, the film is brought to a processing lab, developed into large photographic slides, then studied manually by a military analyst on top of a Light Table to illuminate the image (*fig. 3)*.

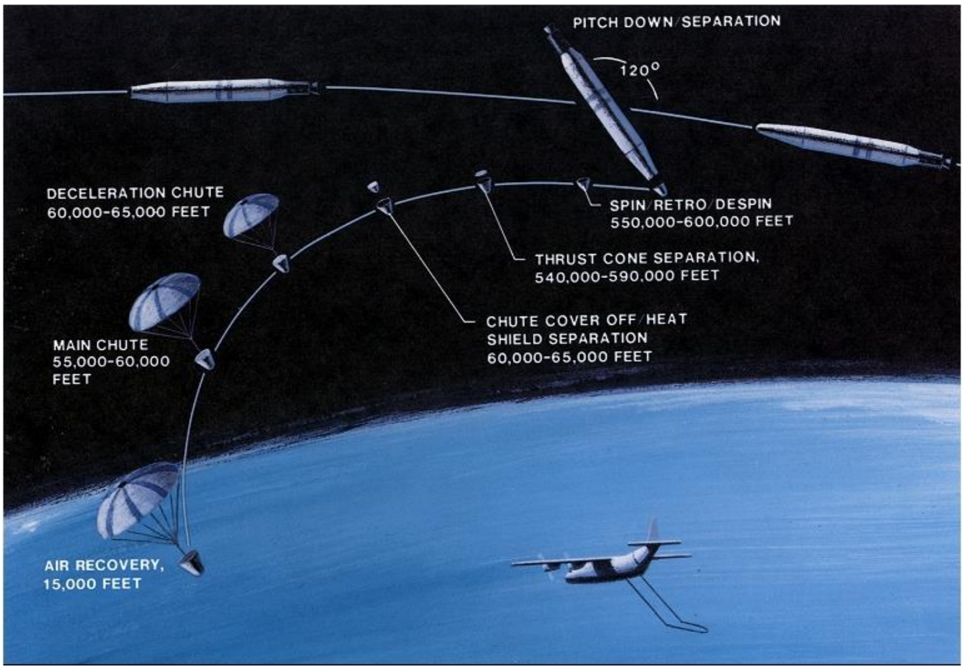


Figure 2. The process of film deployment and aerial capture of photograph capsules from satellites. Source: Wikimedia

Figs 3 & 4. A military analyst examines the type of photographs taken by satellites as part of the Corona program. Source: Wikimedia

Technology has progressed dramatically in both the processes, platforms, and quality, as we can currently receive very high-resolution images sent to our laptops and mobile devices in a matter of hours. However, the origins of this technology, and the great amount of time, cost, and labor involved in acquiring the imagery shows just how valuable remotely sensed data was, and how valuable it continues to be with the ongoing progression being made to this day in its development.

Satellite Imagery: Comparison of Current Sources

Since its beginnings, satellite missions have captured an extensive amount of imagery with variable spatial, spectral, temporal, and radiometric resolution. Given the wide-ranging characteristics of satellite imagery, the possible applications of satellite imagery have also broadened. Applications include but are not limited to identifying and monitoring land use and land change, water resource management, biodiversity and habitat protection, and military intelligence.

Satellite imagery is accessible through numerous avenues, mostly commercial given the great expense of launching and communicating with satellites but there are free resources are available to the public. For example, The United States Geological Survey (USGS) provides free access to archived mid resolution satellite imagery collected during a series of Landsat missions while the European Space Agency grants access to 10 m resolution imagery collected from the Sentinel 1 and 2 satellites.

Very high-resolution (VHR) imagery (> 1 m) is typically accessible through private companies and governments. Gaining access to high-resolution imagery may be costly and can involve extra steps, lengthening the overall process of obtaining and downloading imagery (to be discussed in the following section). It is this high-resolution imagery however, that is necessary to conduct detail-oriented imagery analysis.

The table below compares three different satellites. Satellite specifications greatly vary, which means that the properties of the resulting imagery are very different from one another. Given the wide range of characteristics, you must be familiar with your AOI and your features of interest prior to downloading data to ensure you are selecting the appropriate imagery. Are you analyzing a regional, large scale phenomenon such as deforestation? Then you may want to use a MODIS or Landsat product. Are you interested in small-scale structure counting and damage assessments? Then you may want to consider downloading imagery from WorldView 1, 2, or 3.

Take a moment to compare the properties of each of the following satellites. Please note that there are many other sources of remotely sensed imagery, this comparison simply demonstrates the breadth of satellite properties and their products. A list of additional satellite imagery sources is provided in Appendix II.

Table 1. Comparison of satellite technical specifications

Name	**MODIS**	**Sentinel-2**	**WorldView-3**
Imagery provider	NASA	European Space Agency	Digital Globe
Year Launched	Terra: 1999, Aqua: 2002	2015	2014
Mission Examples	Large scale land change, disaster relief, capturing atmospheric properties such as cloud cover, aerosols, carbon dioxide, and temperature	Land use and change detection, climate change monitoring, disaster relief	Any small-scale analysis including disaster response, environmental monitoring, coastal analysis, land cover classification, feature extraction and change detection
Swath	2330 km	290 km	13.1 km
Spatial Resolution	Bands 1 - 2: 250 m Bands 3 - 7 : 500 m Bands 8 - 36: 1 km	Visible and near infrared: 10 m Red Edge and shortwave infrared: 20 m Atmospheric corrections: 60 m	Panchromatic: 31 cm Visible and near infrared: 1.24 m Shortwave infrared: 3.7 m CAVIS: 30 m
Spectral Resolution	36 spectral bands ranging between 0.4 µm and 14.4 µm	13 spectral bands ranging between 0.443 µm and 2.190 µm*	0.405 µm to 2.245 µm*
Radiometric Resolution	12 bits	8 - 12 bits	11 bits (panchromatic and multispectral) 14 bits (shortwave infrared)
Revisit time or Temporal resolution	1-2 days	10 days	Daily
Cost	No cost	No cost	Variable, contact DigitalGlobe for more information
Link Access	Land cover products Additional product	Imagery access Data access	WFP has Standard Operating Procedures in place to request this imagery

** Spectral range varies depending on the bands and resolutions in consideration. See individual satellite specifications for thorough breakdown.*

The table demonstrates the variations in satellite imagery specifications while the image below visualizes, from left to right, how low, medium, and high resolution appear in an image. Please note that the image is a false color composite (FCC).

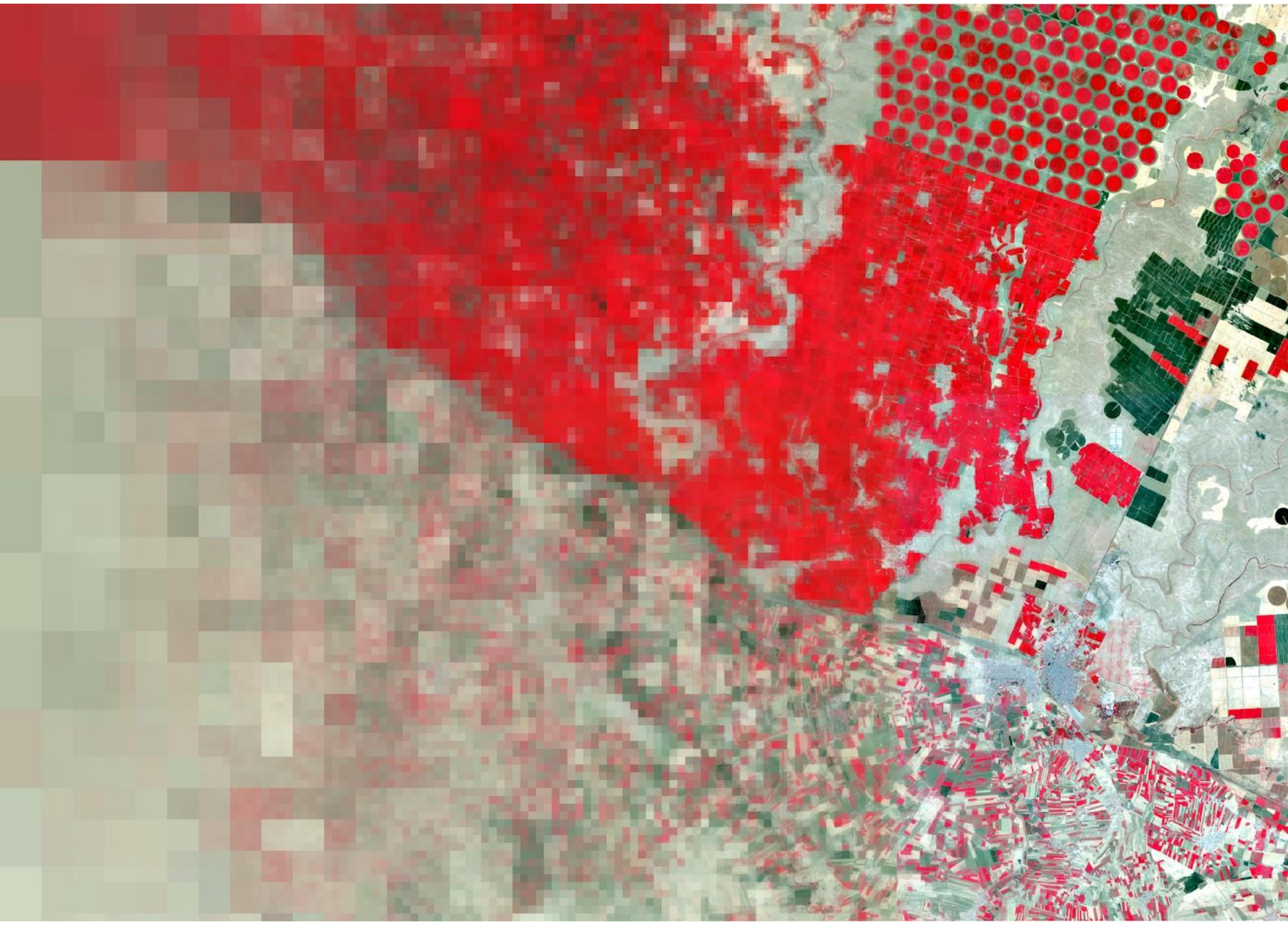


Figure 3. Gradient from low to high spatial resolutions (left to right)

Satellite Imagery: VHR Imagery Background

While a multitude of different imagery sets are used for this analysis, HR and VHR imagery offers a more detailed resolution than other data which can be beneficial for visual identification of objects and phenomena not discernable in lower resolution imagery. The definitions as to what constitutes the differences between HR and VHR imagery can vary from source to source, but VHR imagery is generally considered to have a resolution of less than 1-meter per pixel resolution while HR imagery typically greater than 1-meter per pixel of resolution. For the analytic methodologies taught in this workbook, however, we will be focusing on VHR imagery datasets as opposed to HR.

In VHR imagery, structure types are more easily identifiable, as well as human-related activity, particularly in conflict areas, such as patterns of destruction, looting, infrastructure development, agricultural burning and vehicle tracking. More granular effects caused by natural disasters are also apparent in VHR imagery, where road infrastructure and individual dwellings suffering damage from floods, fire, and winds, can be derived from analyzing the data.

Such VHR imagery typically comes at a cost from commercial providers and their constellation of satellites. The major companies who collect and distribute VHR imagery, such as DigitalGlobe and Astrium can vary in price for a number of attributes, such as if it is panchromatic, multispectral, archival, or a new tasking of an image. Panchromatic archival imagery can range from $10 - $15 per square kilometer (km^2), and multispectral archival imagery can range from $12 - $18. Newly tasked imagery can range from $21 - $24 per km2 for panchromatic, and $21 - $30 for multispectral. It's also important to note that commercial providers require a minimum area per imagery request and that the exact dimensions vary between organizations. These variables ultimately also influence the costs associated with the imagery acquisition.

Though the pricing can be steep, especially when ordering larger images, or multiple images, these providers often times offer discounts for academic institutions and humanitarian organizations, as long as you communicate your needs to them directly.

Satellite Imagery: Downloading VHR Imagery

When the imagery order has been placed, whether it's directly through the satellite company, or through a third-party distributor like Apollo Mapping, you typically receive a link to a cloud storage platform, similar to Dropbox, where your imagery will be ready for download. Keep in mind that VHR imagery can be large in file size, where a full tile of imagery can be as big a several gigabytes. Poor internet connectivity may severely inhibit your ability to download this data.

Some providers, like DigitalGlobe, offer several different licensing packages for imagery as well, often based on a subscription service and directed to organizations utilizing the data for emergency response. This type of platform is often hosted on a browser where collected archival imagery is displayed when an area on a global map is in the browser view and ready for download from a cloud-based library.

Ideally, you want to name your file according to your AOI being analyzed and date of image, store it securely in a folder on your hard drive, and be mindful of storage space if you plan to store several images over time.

DATA PREPARATION

Importing and enhancing satellite imagery are important first steps when approaching imagery analysis. The steps detailing this process in ArcGIS Pro are listed below while the same steps for ArcMap and QGIS are listed in Appendix IV.

ArcGIS Pro: Importing Imagery (video)

1. Launch ArcGIS Pro.
2. Create a new project by clicking *“blank”* under *Create a New Project.*
3. Name the project and choose a location to save the file.
4. Within the *Insert* tab on the data ribbon, open a new map.
5. Within the *Map* tab on the data ribbon, select *“add data”* and navigate to the folder where your imagery is stored
6. The added data will appear as a layer within the *Contents* window on the left-hand side of the interface and is also visible in the data view.

ArcGIS Pro: Image Enhancement

1. When a raster file is selected in the Contents pane, the data ribbon at the top of the page will extend to include an *Appearance and Data* tab, exclusively for raster analysis.
2. Within the *Appearance* tab there are three options that are particularly useful for modifying and improving the appearance of the raster image: 1) Stretch type, 2) Resampling type and 3) Band combination. Explore the available options and combinations.

For visual analysis, we often find that the following combination of settings provides for optimal image enhancement:

1. Stretch type: minimum-maximum,
2. Resampling type: cubic convolution,
3. Band combination: default.

DATA ANALYSIS

Structure Literacy

Context is a major consideration when analyzing variance in structures. In VHR imagery, throughout different AOIs, you will notice that structure types can have many differences in shape, size, and material.

Figure 4. Dolo, Ethiopia is made up of structures of different shapes, materials, and sizes. Source: Google Earth.

Figure 5. A wide range of structure types can be seen in Adjumani, Uganda. Source: Google Earth.

This typically holds true in immediate improvised camps or (informal) settlements, where structures have fewer consistencies. In UN-run camps with standard-issue tents, however, there may be more consistencies.

Often in established camps, tents and structures are typically pitched tarps of a variety of sizes and shapes depending on agency, camp location, structure use, etc. UN agency tents, such as those used by UNHCR or OCHA, are often either blue and white in color in a formalized camp, and can be square, rectangular, or even hexagonal in shape. However, this is not the case for all agencies present in displaced population camps, where structures can differ in color, shape, size, and material.

Figure 6. Kakuma Refugee Camp, Kenya. Source: Google Earth.

Another primary example being the caravan shelters found in camps like Zaatari in Jordan (*fig*. 7).

Figure 7. Standard tents and caravan shelters in Zaatari, Jordan, 2013. Source: Google Earth.

The following examples include examples of structures that appeared in the imagery analyzed of South Sudan and Uganda.

Pajok, South Sudan. 2018.

Examples of a clearly defined structure. It resembles an elevated roof in its geometry and shadow cast on the ground.

Source: © 2018, DigitalGlobe. NextView License.

South Sudan. 2018.

Example of tukuls. While tukuls often blend into the background, the cast shadow and noticeable tip in the center which suggest that these are in fact, tukuls.

Source: © 2018, DigitalGlobe. NextView License.

Adjumani, Uganda. 2018.

Example of an irregular structure, which in this case is a hospital. This can be discovered through background research or inferences can be drawn if the structure appears similar to other hospitals in the region.

Source: © 2018, DigitalGlobe. NextView License.

Uganda. 2018.

Example of conjoined structures. This is a common problem for analysts: how do you know where one structure ends and the other begins?

Source: © 2018, DigitalGlobe. NextView License.

Uganda, 2018.

Example of clearly defined, standard tents. They are all equally sized and are concentrated in the same area, so it is likely that these tents were provided by an organization.

Source: © 2018, DigitalGlobe. NextView License.

Uganda, 2018.

Tukuls and tin-roofed structures are found together in a compounded area.

Source: © 2018, DigitalGlobe. NextView License.

Analysis of VHR imagery can yield some natural obstacles that the analyst should be aware of when conducting identifications of structures, objects, and phenomena affecting the AOIs, whether they are conflict-related or from natural disaster. For instance, structures in locations prone to large amounts of sand or earth being moved by heavy winds, can cover structures such as tents, leaving them difficult to differentiate from the surrounding grounds (*fig. 8*). Similarly, tents that have been in a certain position for an extended period of time can leave a marking or 'footprint' in the earth when it is moved. The appearance of these particular phenomena can closely resemble tents covered in earth, leading to further confusion for the analyst.

Figure 8. Sand-covered structures in Zaatari Refugee Camp, Jordan, 2016. Source: Google Earth.

With these instances, it is important to identify coinciding characteristics that can lead to a more accurate identification of the structures or their footprints. For example, making note of shadowing throughout the image. This can be done by simply observing structures and objects throughout the image and the direction of their shadow placement and see if similar markings coinciding with observed shadows are present on the edges of the individual, potential objects. Conversely, an absence of these shadows could be consistent with a footprint left be a moved structure.

Limitations

There are several factors to be aware of when analyzing VHR imagery that could present the analyst with a disadvantage. The most common limitation with this data is cloud cover, and several additional factors can heighten the chances of this occurring of which the analyst should be mindful (*fig. 9)*. Cloud cover may be attributed by geographic location, proximity to water bodies, frequency of storms, and seasonal cycles.

Figure 9. Cloud cover in Pajok, South Sudan 2018. Source: © 2018, DigitalGlobe. NextView License.

A minimal amount of cloud cover, or similar phenomena like atmospheric haze, can sometimes be adjusted for by manipulating contrast in the image to identify objects through thin cloud occultation, but thick cloud cover can make it difficult-to-impossible for analysis if your AOI is obscured. In addition, shadows or trees can also obstruct features in the imagery, making them very difficult to capture (*fig. 10*).

Figure 10. Structure partially covered by a tree in South Sudan, 2018. Source: Google Earth.

When analyzing an AOI with several images over multiple dates, or conducting multi-temporal change detection with two different images, be aware of georeferencing, orthorectification and calibration issues between the data sets. Often, this can cause a misalignment between the images, and the analysts can be misled assuming that it is correctly aligned. However, with the more seasoned satellite companies, this is less of an issue, or at least the misalignments are minimal in both difference and occurrence.

When identifying and analyzing smaller structures, objects, or small-scale phenomena, the resolution of the data is important, and sometimes, imagery with a higher pixel count per cm can make it more difficult to identify objects (*fig 11)*. For example, in observing a location with an improvised or informal camp set-up, where there are small numbers of miniscule

Figure 11. Very small structures and objects in Palorinya Refugee Settlement, Uganda, 2018. Source: © 2018, DigitalGlobe. NextView License.

structures such as a lean-to shelter, these structures may be more easily identifiable in VHR imagery that is 30-50 cm per pixel as opposed to 1 m per pixel resolution imagery. In summary, be mindful of structure size limitation, as no matter how high the satellite imagery resolution is, an object may be too small to verify if it is a structure or not, as may be the case with the example mentioned above.

The last limitation to consider for the work in this guide are complications due to very high numbers of structures being counted. When trying to estimate a large settlement population, such as Adjumani, Uganda, there can be thousands of structures being counted in the software, and this can lead to multiple technical complications. When placing a large number of icons with a count-feature function, it can take a toll on your computer's processing power and severely slow down your operation. In some cases, this increased processing load can cause the software to crash, resulting in the loss of unsaved changes. That’s why it is important to save your work often during the process of analysis and to divide and save large-scale structure counts to multiple files.

Structure Counting Techniques

Conducting structure counts requires concentration and can take anywhere between a few hours to a few days. The ease of conducting structure counts is affected by the size of the AOI, contrast of the feature of interest and the background, the heterogeneity of the landscape, among other variables. Given the lengthy and often tedious process, it is important to identify a counting technique that you find most effective and efficient. Every analyst devises their own approach once they become familiar with the structure counting process and you are encouraged to do the same. Below there are steps detailing how to create and edit a blank data file. These steps are followed by recommended structure counting techniques.

ArcGIS Pro: Creating and Editing a Blank Data File (video)

1. In the Catalog pane on the right-hand side of the interface, navigate to your project data folder. Within the folder there will be a geodatabase subfolder with the extension .gdb.
2. Right-click within the .gdb folder >> New >> Feature Class.
3. Define a filename and set the feature class type to point. You may leave the remainder of the parameters as default. When completed, select Finish.
4. The newly created file will appear in the .gdb folder.
5. To collect structure counts in the blank file, add the data layer to the map contents. It is imported the same way as other data layers.
6. When added to the Map, highlight the data layer in the Contents column and navigate to the Edit tab >> Create.
7. A window titled Create Features will appear on the left-hand side of the interface. Select the blank file you created and under the file name select "Point" to create a new point. Notice that the cursor changes when you hover in the data view.
8. To count structures simply click on the structure to create a point
   - To delete all edits after the most recent save: Edit tab >> Discard.
   - To delete a single edit, highlighted in cyan: Edit tab >> Select >> Delete
9. Throughout the structure count, frequently save your changes Edit tab >> Save
10. To end an editing session, navigate to the Map tab on the data ribbon and select Explore
    - To delete points after editing, right click on the data layer in the Contents pane. Open the attribute table and select the point to delete. Right click on the attribute row to select and delete the attribute.
    - Alternatively, you can navigate to the Map tab >> Select >> Right click and delete

Take a moment to consider and apply the following two commonly used structure counting approaches. Which one do you prefer? If neither of these techniques feel good, what can you change to make them effective? Remember that structure counting can be a tedious process. It is important to maintain your concentration throughout your analysis to ensure high quality work.

Analysis Methods (video)

Method 1: Scanning and Panning

1. Open the image in consideration
    1. Do you have a clearly defined AOI boundary?
        1. If yes, zoom to the AOI extent
        2. If not, familiarize yourself with the entire scene. What are the image characteristics? Consider the image at different zoom levels
    2. At what zoom level are the features of interest clearly visible? Ensure that you are able to discern the features from their surroundings
2. Once you've established an encompassing zoom level, shift to the top left corner of your AOI
3. Count each individual structure in the data view. Once all the structures in view have been counted, shift right and repeat. Continue this process until you've reached the top right corner of the AOI.
    1. Once all the structures have been counted in the initial row, pan down and repeat the process from right-to-left or left-to-right

Method 2: Gridded

1. Open the image in consideration
2. Select the Create Fishnet tool from the Data Management Toolbox under the Analysis tab and enter the parameters accordingly
    1. Output feature class: preferred name
    2. Template extent: set to image extent (this will auto populate most of the fields)
3. Cell size height and width: based on preference. Note that the units are that of the imagery
4. The Create Fishnet tool will create a grid over the defined extent. Use this grid as guidance when conducting structure counts, meaning, that you should count all the structures in one box prior to moving on to the next box. Like this, you're able to count structures within the grid in no particular order.

To ensure you do not lose track of your counting location, it is recommendable to stay at a consistent zoom level. However, when you feel it is necessary, you should pan out to get a clear overview of the larger area to ensure no structures have been missed. Once you're satisfied with the result, reorient yourself to the initial zoom level and continue counting.

Change Detection (video)

A completed structure count provides an indication of how many structures exist in an AOI at a given time. As time progresses however, the number of structures may change. This is particularly relevant to regions that experience a change in population (due to population growth, migration, disaster, conflict, etc.). Multi-temporal change detection (MTCD) is used to monitor an AOI over an extended period of time and can be done in a variety of ways, two of which are described below.

Toggle between layers

When you add data to the map layout in ArcGIS Pro, they are listed in the Contents column in the map view. The order in which the layers are added to the map are the order in which they are displayed in the data view. This means that the most recent layer addition will appear as the topmost layer as listed in your Contents column and on the map itself. To reveal the layers below, you must uncheck all the layers above the layer you would like to visualize.

When multiple images of the same AOI are imported to ArcGIS Pro, they will layer on top of one another. Toggle back and forth between the layered images by checking and unchecking the checkboxes next to the image file name. As you toggle, identify and characterize any changes in the landscape, considering the following questions. Was the image taken at the same time of year? Does the vegetation look different? Was the image taken at a different angle and time and of day (notice the size and direction of shadows)? Does the imagery exactly align? The two images will most likely appear different given weather conditions, collect time, and collection angle. Cautiously analyze the changes in imagery.

It may be helpful to add the completed structure count points to the map so that you can visualize which structures you have already captured at one date. To capture change, simply copy the shapefile and paste the copied file in the Contents column. Rename it to reflect the new date. Then, enable the editor toolbar to add, delete, or move existing points in the data file.

While doing this analysis, it may also be helpful to make raster layers transparent. To make a layer transparent, navigate to the Appearance tab on the data ribbon. In the Effects section, you are able to modify the transparency of the selected layer.

Link views

Another way to conduct change detection is to *link views* in ArcGIS Pro. This feature allows one to open multiple images of the same location and display them side-by-side. To do this, open a new map and reposition it by simply dragging the top bar of the map to the side to align it with the original map. An icon will appear as you do this, which should assist you in placing the maps side-by-side. Once the images are displayed, as you pan through one image, the linked image will also shift in the same manner. This is incredibly useful when considering multiple dates, since it will provide a clear visual overview of what has changed over time. Additional data layers may also be linked, including basemaps, vector layers, land cover maps, or additional raster layers.

To link views in ArcPro, go to View on the data ribbon. Within the View tab, click on the Link Views button. Notice that a chain icon appears on your map tab, which indicates the map window is linked. To link this primary map to additional maps/imagery, add a new map and import data to it. Notice that the chain icon will also appear on the newly added map window. As you pan through one map, notice that the other will move along.

If the linked maps appear at different scales, enable the center and scale feature in the Link Views dropdown menu. Like this, the map scales should be matched and you're able to analyze the images at the same scale. To link the images at different scales, simply disable this option.

Damaged and Dismantled Structures

The results of both natural disasters and conflict scenarios can present the analyst with a number of damaged structures, often with patterns and visual signatures that are unique to the events that occurred. It is critical to recognize these particular patterns when analyzing imagery in these scenarios to gain a comprehensive and more accurate understanding of the damage sustained by these structures.

In conflict, signatures of damaged structures can be readily identified to an analyst when considering the methods of ground actors in the destruction and dismantling of structures. Incendiary, explosive, and combustible materials used during conflict can leave specific signatures to a structure, thus indicating a damage related to the conflict event.

Figure 12. Damaged structure in South Sudan, 2018. Source: © 2018, DigitalGlobe. NextView License.

For instance: tukuls, or traditional dwellings used throughout Central and Eastern Africa, are made of natural organic materials, such as wattle and daub, with thatched roofs. These organic materials, when in contact with an incendiary, can burn and char leaving specific, identifiable signatures in the imagery. In observing imagery of Pajok, South Sudan from January of 2018, we located several examples of individual, intentional destruction of tukuls. Compared with imagery taken six months prior, the signatures are apparent of the remains of the tukul walls leaving a distinctive circular shape that will be observed in subsequent imagery examples in this guide.

One often-employed method of intentional damaging of structures in these areas is for an actor to approach a tukul directly and burn the roof of the structure. This effect collapses the highly-combustible thatched roof to fall within the wattle-and-daub confines of the tukul. The visual signature of this effect can reveal a charred ring around the perimeter of the tukul from falling ash, to a dark, ashen center with white ash of burned material within the tukul confines *(fig. 13*).

Figure 13. Charred tukuls in Pajok, South Sudan 2018. Source: © 2018, DigitalGlobe. NextView License.

It is important to note that in events such as these, where the imagery shows the destruction of structures of an AOI in a conflict area, to make sure of surround signatures in the earth that could differentiate an attack from an incidental event. Phenomena such as structures being individually burned and scorched earth connecting the structures shows that the results are consistent with intentional burning or destruction. The reason for this is that in areas that experience dry seasons of desiccated vegetation, the ground is prone to fire which can spread and burn structures to the effect of it being damaged or destroyed. However, it should be noted that this widespread fire can be ignited intentionally as an act of arson.

Figure 14. Pajok prior to conflict-related damage, South Sudan, 2017. Source: © 2018, DigitalGlobe NextView License.

Beyond structures being damaged by means of fire or ordnance, another visual identification of structure damage in conflict areas is the roofless structure without any burn signatures. The reasons for this phenomenon can vary. One of the major reasons for this is that if the roofs are made of a metal, such as zinc, that are valuable materials to both the inhabitants of the structure, and possibly, the actors initiating the attack. As in the case of fighting in South Kordofan in Sudan during the conflicts of 2012, inhabitants of the structures would dismantle the roofs themselves and take the material with them if they were escaping their locale from an impending attack, but the attacking actors would also be reported to be taking rook materials that were left behind because of their value. However, structures with combustible roofs could have been destroyed by means of fire, and the image being analyzed could show no signs of scorched earth simply due to a lengthy period of time between the attack and the date of the imagery collect reveal earth to change and vegetation to grow during that time. This can be seen in Pajok, as subsequent imagery taken six months after the January 2018 image shows that healthy vegetation has overgrown many of the remains of the destroyed tukuls previously observed. That is why an analyst should be mindful of the date of the event and the date of the imagery being analyzed.

Figure 15. Dismantled structures in Pajok, South Sudan, 2018. Source: © 2018, DigitalGlobe. NextView License.

In natural disasters, there are similar signatures to recognize in the analysis of damaged and dismantled structures as mentioned above, as well as some variance. One of the most often identified forms of structure damage during a wind disaster is the roofless structure. In appearance, this damaged structure is similar to an intentionally dismantled structure, as the analyst can often identify the walls and room partitions within the perimeter of the structure. If the imagery has been collected before and considerable clean-up operations were initiated after a storm has contacted an AOI, vast amounts of debris and scattered material in disarray can also be identified, however, due to limitations in the resolution of the imagery, such haphazardly placed material is generally unidentifiable.

In areas affected by extreme flooding, MTCD of baseline imagery compared with imagery collected after the flood can reveal structures that have been impacted by the flooding waters. Such as with the case with Dikwa Camp, in Borno State, Nigeria. This camp, which, throughout the summer of 2016, was observed by imagery analysts at growing at an alarming rate due to the massive increase in structures of a relatively short period of time, suffered a severe flood during this period (*fig 16, 17)*. Imagery collected shortly after the flooding occurred revealed a significant portion of the camp suffered extensive intrusion of flood waters, including structures of use for food security, such as communal kitchens inside of the camp.

Subsequent analysis of imagery being collected over the area showed that within two months, the entire camp had been ‘dismantled’, or in other words, every structure within the camp confines had been removed (*fig 17*). This could be due in part to the less permanent structures, like tents, suffered severe damage, but it could also be that the area was also prone to flooding, possibly built on a decline of earth, making it easy for flood waters to collect and remain stagnant. Interestingly, further analysis of imagery being collected over Dikwa revealed a massive rebuilding of the camp, or what was to become camps (*fig. 18*). At least seven different locations throughout the town of Dikwa itself showed the placement of new civilian tents in both an organized and improvised fashion. Also, the addition of more permanent-use structures, such as those for agency use, were also being constructed.

9 May 2016

13 June 2016

23 June 2016

Figure 16. Progression of growth of a displaced settlement camp in Dikwa, Nigeria Source: Terra Bella

4 July 2016

5 September 2016

10 October 2016

Figure 17. Flooding in and surrounding the displaced population camps in Dikwa, Nigeria. Source: Terra Bella

1 July 2016

2 September 2016

10 October 2016

Figure 18. As a result of the floods, structures that were previously located in the camp outside Dikwa town, are now resettling throughout the town. Source: Terra Bella

Advances of Automated Structure Counting Techniques

The visual structure counting techniques described in this workbook reflect the methods commonly used by data analysts in the humanitarian sector. Visual analysis is time intensive and requires a high level of concentration to ensure that counts are accurately conducted.

There is a urgent need to develop (semi) automated structure counting methods to accelerate the structure counting process. The implementation of such methods would minimize human error and make time for additional analysis. This is especially relevant when conducting near-real time monitoring of settlements in complex emergencies where rapid population estimates are needed to inform resource allocation and distribution.

Data scientists around the world have used machine learning and object-based classification in addition to complex algorithms to address the issue at hand (Appendix VI). Machine learning is a pixel-based approach that requires input data to inform image classification. Object-based classification takes a set of neighboring pixels and groups them as an object based on the similarities of the pixels (i.e. a structure or a tree) prior to image classification. Often times, object-based analysis relies on contextual analysis and frequently incorporates rule-based techniques. Such rule-based techniques may include criteria about the feature size, shape, and any other relevant characteristics. These techniques have been applied in various settings including metropolitan cities, refugee/IDP camps and rural settings with varying levels of success. Automated counting techniques perform fairly well in planned settlements in which structures are spread out and clearly identifiable while they perform less accurately in unorganized settlements where structures blend into the landscape and are difficult to distinguish from one another. The latter scenario is one that humanitarians encounter more frequently.

So far, (semi) automated techniques are not well optimized for the work humanitarians frequently encounter and the complicated algorithms and proprietary software platforms require a high-level understanding of the subject, making it difficult for data analyst with little to no prior knowledge on the subject to apply the methods.

To date, visual analysis of such complex landscapes are most reliable when conducted manually. The human eye better recognizes human patterns and behaviors and is able to discern anomalies in imagery, which could include a sudden appearance of graves, damaged structures, military formations etc. Nevertheless, the growing need of automated feature detection has attracted data scientists to continue to explore the subject.

DATA PRODUCTS & PRESENTATION

Map Design

The importance of cartography, the art and science of map design, is often overlooked in data presentation. Map design is critical to ensure your data and findings are effectively communicated to your audience. In the presentation of such data, several map elements are required including a north arrow, scale bar, legend, and title. The legend should comprise of a description of your map symbology and layers while the title should provide details about the AOI including the location name and date. Additional elements such as a regional map for context, organization name, source name of the imagery and a total structure count number provide valuable information for your audience.

In addition to the inclusion of the described map elements, the positioning of these elements in your map document is also an important consideration. Ideally, you should strive for balance, meaning that there should not be too much empty space and the information should not all be crowded into one corner of the page. Keep in mind that the title should be descriptive and clearly presented. The title should be the first text element your audience reads, so you may want to consider the text size, font, and positioning on the page. The map layout included in Appendix V provides a suggested example of a map layout. Keep in mind that the layout is one example of map design. There are many effective ways of communicating your data, which you may explore by searching additional examples or by moving around individual elements.

Sharing Data

You can share your map with the intended audience in a variety of ways, several of which have been outlined below.

Project package (.ppkx): One way to share your data is to directly share the map (.aptx) file and the geospatial files used. First, identify where your project was saved on your computer. ArcPro packages the the .aptx file, the geodatabase and any other additional project files in the project folder. If you choose to share the entire folder, the best way to share it send a compressed folder. To compress, otherwise known as zipping a folder, right click >> Send to >> Compressed (zipped) folder. By sharing the .aptx file and the associated data layers you give the receiver the opportunity to work and make changes into the map document. Unfortunately, the majority of products created in ArcGIS Pro can only be opened in versions of ArcPro. However, please note that if a project is opened in an older version of ArcGIS Pro, the document may be downgraded. You can create many additional products including map packages, layer packages, tile packages and others.

Geodatabase: Unlike the project package, the project geodatabases created in ArcGIS Pro on the other hand, can be opened in software that previously accepted geodatabases including ArcMap and QGIS. The best way to share a geodatabase is by selecting the entire .gdb folder. Feature classes and datasets have many associated extensions that can be easily missed so copying individual files directly from a folder is very difficult to do. If you prefer to only share one file from a geodatabase, it is recommended that you move the file into another geodatabase through the catalog in ArcGIS Pro.

Non-spatial: You may also export your map document as a JPEG, TIFF, PDF etc. These file formats may be accessed by a variety of software that do not have geospatial capabilities such as PDF readers. This may be the desired way of sharing information if the recipient does not have access to ArcGIS Pro or other geospatial platforms. Please note that spatial information in the exported document can generally not be modified but design changes can be made when exporting as certain file types, such as .AI which can be modified in Adobe Illustrator.

Imagery Briefs

An imagery brief is the equivalent to a summative presentation of a project, whether it is ongoing or completed. An imagery brief should inform the intended audience of the project progress and generally includes an introduction, overview of the objectives, study area indicated by a map for context, methods, results, and conclusion. Given that the focus is on imagery analysis, the presentation should primarily consist of imagery rather than text. Additional graphics such as charts and diagrams are also encouraged to supplement imagery analysis. The maps included in the presentation should adhere to the general rules of map design and should be presented as a completed map document.

CONCLUSION

The incorporation of VHR satellite imagery analysis has proven hugely beneficial in the humanitarian sphere. The incorporation of the technology into the sector allows for the identification features and processes in inaccessible, remote, and large areas. Multi-temporal change detection further allows for rapid monitoring of population movement and assessment of damage caused by disaster or conflict.

Collaborative efforts between the Vulnerability Analysis and Mapping unit at the World Food Programme and the Signal Program on Human Security & Technology at the Harvard Humanitarian Initiative demonstrate several of the effective ways in which remote sensing can be incorporated into the humanitarian sphere. Over the last two years, the collaboration has led to the successful analysis of camps and settlements, population movement, damage attributed to conflict, among many other focuses.

The analysis techniques detailed in this guide provide an overview of some of the methods and software platforms used by analysts for the duration of this project and more generally, by many analysts in the sector. Perhaps most important is the contextual understanding and background research prior to conducting analysis. The analyst should become familiar with the landscape and the features visible in the AOI and should think critically throughout the analysis process. As an analyst, you may face some very difficult tasks of monitoring the growth of refugee/IDP camps or informal settlements. Such assignments can take many hours and small structures may be difficult to identify. You may also notice irregular features in your AOI, whether that is a cemetery, an agricultural plot, a herd of cows, or an unusual structure. Additional research can help identify such inconsistencies, and you may want to consult another analyst.

While the interpretation and analysis of satellite imagery is not an easy or straightforward task, the potential information an image may hold is infinite. Whether the data reveal previously unknown information, are supplemental to research conducted on the ground, or simply verify previous findings, imagery analysis has immense potential when incorporated into this line of work.

APPENDIX I: TERMS DEFINED

Archival – Historic satellite imagery that is stored in a database. Depending on the archive, the imagery may date back two years, two decades, or beyond.

Area of Interest (AOI) - A delineated area that captures feature(s) of interest.

Bands – Also referred to as a channel which collects incoming electromagnetic energy at different wavelengths. I.e. In Landsat 7, band 1 captures 0.45 – 0.52 micrometers (blue), band 2 captures 0.52- 0.6 (green), and band 3 captures .63 – 0.69 (red).

Band Combination- The imagery you receive will typically be downloaded as a true color composite (TCC), which suggests that the colors are true to reality. This multispectral imagery is created due to mixing of primary colors: red, green, and blue (RGB). In this case the image colors will appear as they do in a photograph, allowing us to associate greenery with vegetation and shades of brown as soil or dirt etc. However, there are several instances in which a false color composite (FCC) is recommended.

Calibration - Matching and aligning pixels to real life to ensure imagery is reflective of reality.

Data view - View intended for the visualization and analysis of all data layers. The data view does not include map elements that are found in the Layout view.

False color composite (FCC)- A false color composite is created when the order of the satellite image bands are altered. So, while the image is recorded as RGB, the order may be modified to display GBR or BRG which will modify the colors of the image. Additionally, false color composites can include wavelengths beyond the visible spectrum such as the near infrared (NIR) or shortwave infrared (SWIR). FCCs of various combinations may reveal information that is not otherwise visible or apparent in TCCs.

Geodatabase - Folder that hold geospatial data in a variety of formats. Geodatabases allow for simple organization of data, which can otherwise get convoluted.

Georeference - Process of aligning data to a coordinate system. When a geographic coordinate system is assigned to the data it can be used to measure units on the ground and work with other georeferenced datasets to minimize misalignment.

Lean-to shelter - Simple roof which leans on an adjacent structure, often made with natural materials or plastic tarp.

Multispectral – When a satellite captures wavelengths beyond the visible portion of the electromagnetic spectrum. Frequently this will include the near and shortwave infrared bands

Orthorectification - Minimization or elimination of geometric distortions in the image that may have been caused by the satellite sensor or the appearance of the earth's surface. Orthorectification is done by stretching the image.

Panchromatic – Single band that captures the reflectance of the feature its imaging in greyscale. Panchromatic imagery is typically higher resolution than multispectral imagery

Pansharpen - Create a colored high-resolution image by merging a very high-resolution panchromatic image with a lower-resolution multispectral image. Eg. when a 0.3 m panchromatic image is merged with a 1 m multispectral image using pansharpen, a 0.3 multispectral image is derived.

Radiometric resolution - Refers to satellite sensor sensitivity to incoming energy. As the radiometric resolution increases, the ability to detect subtle changes in incoming energy is improved, allowing for clearer feature definitions in an image.

Resampling - Interpolation of new cell values. Nearest neighbor is typically used for discrete data while cubic convolution, bilinear interpolation, and majority are used for continuous data. For this type of analysis, we recommend using cubic convolution because it sharpens the image, typically allowing for better feature detection.

Spatial Resolution - refers to the smallest possible feature that the sensor can detect, a pixel. High resolution (i.e. 1 m) will reveal more details than mid-resolution imagery (i.e. 30 m)

Spectral resolution - Satellite imagery is composed of wavelengths that are grouped into bands. The way in which they are grouped is referred to as the spectral resolution.

Stretch type - When a raster image is stretched, properties such as brightness and contrast are modified. Click through the various stretch options to see how they change the appearance of the image and choose one that maximizes the enhancement of the image in consideration. In most cases, we find that the minimum-maximum stretch is most suitable. The minimum-maximum stretch is a linear function that spreads the pixel values to range from 0-255, improving the contrast between features of interest and the background.

Tasking - Requested imagery collection of a target area, which often requires modification to the satellite path.

Temporal resolution – The time it takes for a satellite to image a location a second time

APPENDIX II: ADDITIONAL SATELLITE INFORMATION

Besides MODIS, Sentinel-2, and Worldview- 3, there are many additional satellites that collect satellite imagery. Below you will find a comprehensive list of additional satellite sources. However, please note that this is not an exhaustive list of resources- there are many additional satellites that collect imagery that are not listed below. If you come across inactive satellites, know that historic imagery archives for those sensors may still be accessible.

Landsat Series 1 – 8: The Landsat series has a large mid-resolution imagery archive, as the Landsat mission has been collecting imagery for over 40 years. The project resulted from a partnership between the National Aeronautics and Space Agency (NASA) and United States Geological Survey (USGS). Currently, the active satellites include Landsat 7 and 8, with Landsat 9 expecting to launch in December 2020. While additional satellites are offline, collected imagery can still be acquired from USGS. Landsat imagery is free and can be downloaded via the USGS Earth Explorer. Other data layers and sources are also available on Earth Explorer.

Sentinel 1 – 2: Hosted by the European Space Agency, the Sentinel missions have launched sensors with various capabilities (Sentinel 1 - 6). Sentinel 1 - 2, each of which comprise of twin satellites A and B, are most relevant to the analysis discussed in this guide. A very important distinguishing factor between Sentinel-1 and 2 Is that Sentinel-1 is a radar, active sensor while Sentinel-2 is an optical, passive sensor. Learn more about Sentinel 1 - 2 and download Sentinel imagery at no cost through the Copernicus hub.

SPOT 6 – 7: Satellite Pour l'Observation de la Terre, or SPOT, is a French satellite system hosted by the French national space agency. Both satellite constellations were launched within the last 6 years and have panchromatic data at 1.5 m resolution and multispectral data at 6 m resolution. SPOT 6 - 7 will eventually replace and improve upon previous satellite missions. Learn more about SPOT 6 -7.

WorldView 1 – 3: DigitalGlobe hosts a range of satellites capable of collecting HR and VHR imagery. The WorldView satellites collect panchromatic and multispectral imagery at varying spatial resolutions. Learn more about the WorldView satellite constellation and other DigitalGlobe Products. Imagery acquisition comes at a cost and must be directly requested through DigitalGlobe, however reduced pricing may be provided for humanitarian organizations and academic institutions.

APPENDIX III: TOOLS & DATA PRODUCTS

Tools

Collect Earth: A data collection tool used with Google Earth that allows users to visually analyze HR and VHR imagery.

GeoODK: An Android Application that allows the user to collect and store geo-referenced information and visualize, analyze and interact with ground data.

Google Earth Engine: Google Earth Engine is a powerful cloud computing platform that offers access to petabytes of satellite imagery and geospatial datasets.

SEPAL: System for earth observation, data access, processing, analysis for land monitoring

WFP VAM Roof Detector: Upload a satellite image (.tif) file and an estimate hut count will be produced.

Tools to consider in geospatial software platforms:

- Fishnet: Creating a grid, otherwise known as Fishnet in the ArcGIS suite. This can assist in the organization of analysis
- Measurement: Using a measurement tool to determine the area, distance, or size of a feature in your AOI.
- Clip: To modify the extent of a file to match that of another. For example, if you have conducted a structure count covering 25 km^2 but you only want to consider 2 km^2 instead, you can clip your structure points to a boundary of 2 km^2.

Data products

Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS)

- Global rainfall dataset (1981 - near present)
- High resolution gridded satellite data supplemented with in situ data collection
- Cost: no cost
- Uses: short-term and long-term monitoring agricultural production, drought and rainfall patterns, vegetation health, environmental

monitoring. Important for understanding and monitoring the seasonal trends and/or land cover impacts in AOI.

- Useful links: VAM Seasonal Explorer, Climate Hazards Group

European Space Agency Climate Change Initiative (ESA CCI)

- Land cover product (1998 - 2012)
- 300 m spatial resolution
- Cost: no cost
- Uses: composite land cover products that can assist in monitoring forest cover and agricultural settlements. The ESA CCI has additional products for soil moisture, fire and other environmental factors.
- Useful links: CCI Dashboard,

Joint Research Center Global Surface Water Explorer (JRC GSWE)

- Spatial and temporal profile of surface water (1984 - 2015)
- 30 - 60 m resolution (composite of Landsat data)
- Cost: no cost
- Uses: monitor the temporal profile of surface water availability in relation to agricultural productivity and changes in the surrounding settlements.
- Useful links: Global surface water explorer, global surface water FAQ, high-resolution mapping of global surface water and its long-term changes

APPENDIX IV: ANALYSIS IN ArcMap & QGIS

Analysis in ArcMap

Importing Imagery

1. Launch ArcMap and select a blank map as the map template.
2. To add data, navigate to the Add Data button in the toolbar. In the dialogue window add a new folder connection. This will open another window in which you should select the folder containing the relevant data.
3. Add the folder connection and add any necessary datafiles to the blank map. Now that the folder containing data is connected, you may easily access this folder via the Catalog which should appear on the right-hand side of the interface.
4. If you're opening imagery for the first time a pop-up dialog will appear. You may accept the default options, which will automatically add the data to your data view. Note that the individual data layers are displayed in the data view and in the Table of Contents on the left-hand side of the interface

Image Enhancement

1. To modify image appearance in ArcMap, right click on the layer of interest and navigate to Properties in the drop-down menu.
2. Within the layer properties navigate to symbology >> RGB Composite. You can modify the image composite at the top of this section by changing the order of the bands.
3. In the Stretch section of this window modify the stretch type.
4. Within the layer properties navigate to Display. Within the Display window you can modify the Resample type and modify variables such as contrast, brightness and comparison.

For initial analysis, we often find that the following combination provides for optimal image enhancement:

1) Stretch type: minimum-maximum,
2) Resampling type: cubic convolution
3) Band combination: default.

Creating and Editing a Blank Data File

1. Expand the Catalog and right click in your desired folder location >> new. Note that there are many file formats to work with. We recommend creating a new file geodatabase, in which you would have to create feature classes. You may also choose to create a shapefile instead of a geodatabase and feature class.
2. Whichever file format you choose, select the type and complete the dialogue to create a new file. The created file is added to the table of contents on the left-hand side of the interface.
3. To populate the blank file, the editor toolbar must be enabled. To do this navigate to the Customize tab at the top >> Toolbars >> Editor.
4. To start an editing session, select the dropdown menu on the editor toolbar and choose "start editing". This will enable the Editor toolbar.
5. To create new features select the Create Features tool. In the Create Features dialogue select the shapefile to edit and select the construction tool to be a point.
6. To count structures simply click on the structure to create a point.
7. Throughout the structure count, frequently save your changes Editor dropdown menu >> Save Edits.
8. To end an editing session, navigate to the Editor dropdown menu and Stop editing

Deleting data points

During an editing session

- To delete all edits made after the most recent save: Edit tab >> Discard
- OR, to delete a single edit, visible in cyan: Edit tab >> Delete

After editing

- Right click on the data layer in the Contents pane. Open the attribute table and select the point to delete. Right click on the attribute row to select and delete the attribute.
- OR, Map tab >> Select >> Right click and delete

Creating a Map Product

Map Layout

1. Under the View Tab, select Layout View.

2. The layout view will open and the Layout toolbar will be activated. There are several settings in the Layout toolbar that may be modified.
3. The primary map components such as title, scale bar, north arrow etc are listed under the Insert tab at the top of the page. Explore the options and refer to the map layout example provided in this guide

Sharing Data

Note: this is not an exhaustive list of export types. See the ArcGIS website for more.

Export Type	Process	Reasoning
Export Map	File >> Export Map >> Name file and specify file type	Map layouts are the best way to share information if ArcGIS is not accessible to others.
Map Package	File >> Share as >> Map Package >> Complete the required fields in the Package Project Window >> Analyze and Share	If you anticipate another party to work on the project, share the entire project package. This format will maintain all map components
Geodatabase	Navigate to the .gdb file on your computer >> Right click >> Send to>> Compressed (zipped) folder	Share a geodatabase if only the files need to be modified or opened by another user
Feature Class to Shapefile	In the Catalog >> Right click on file >> Export >> Feature Class to Shapefile. Complete required fields	A shapefile is a more common data format
Exporting Shapefiles	Navigate to project folder on computer >> Select all file extensions (.prj, .dbf etc) >> Right click >> Send to >> Compressed (zipped) folder	All files associated with shapefiles must be selected and exported together. If they are not exported together, the file will not open

Analysis in QGIS

Imagery Import

1. Launch QGIS and open a blank map: Project >> New. Or, click on the blank page icon
2. To import imagery Layer >> Add Layer >> Add Raster Layer or click the shortcut icon  on the left-hand side of the interface. Navigate to the folder containing your data and add the individual files. It will be added to the Layers Panel and will open in the data view Alternatively, you can navigate to your folder through the Browser Panel on the left-hand side of the page and drag it into the Layers Panel
3. Once the data has been added it should appear in the data view

Image Enhancement

1. To modify image appearance, right click on the raster layer in the layers panel. Navigate to the layer properties >> Style
2. To modify…
    - Band composite: Create FCCs in the Band Rendering section
    - Stretch: Change the contrast enhancement within the band rendering portion
    - Modify additional image properties: see Color Rendering section
    - Resampling: modify properties in the Resampling section
3. Apply all changes

Creating and Editing a Blank Data File

1. Layer tab >> Create Layer >> New Shapefile Layer
2. The layer type must be set to point and you may leave the remainder of the dialogue as default
3. The new layer will appear in the Layer panel. To begin editing right click>> Toggle Editing
4. When enabled, the editing toolbar becomes active, select the Add Feature button to add points
5. Every time a new point is added, a window will pop-up asking to assign a value to the id field. Leave it blank and click ok. By leaving the ID value field empty, the attribute table will simply list that entry as NULL. When conducting structure counts, typically the numeric count is the most important output. To find the total count value right click on the data layer

and open the attribute table. At the top of the attribute table, the total feature count will be visible.

6. Frequently save your edits while the structure count is conducted
7. To end and editing session, right click on the data layer and disable Toggle Editing. To delete data points, the editing feature must be enabled. You can delete feature points in the attribute table.

Creating a Map Product

Map Layout

1. To create a new map layout: Project tab >> New Print Composer >> Choose file name
2. Add Map by selecting the icon on the left-hand side of the page. Size the map accordingly and your data will appear
3. On the left-hand side of the composer there will be additional icons that will allow you to add map features including the North Arrow, Scale Bar, and Legend. Each of these components are necessary in the creation of your map. Explore the available options, you may add any additional relevant information. To modify the elements, explore the options in the Atlas generation on the left-hand side of the page. Refer to the map layout provided in this guide to influence your map design

Sharing Data

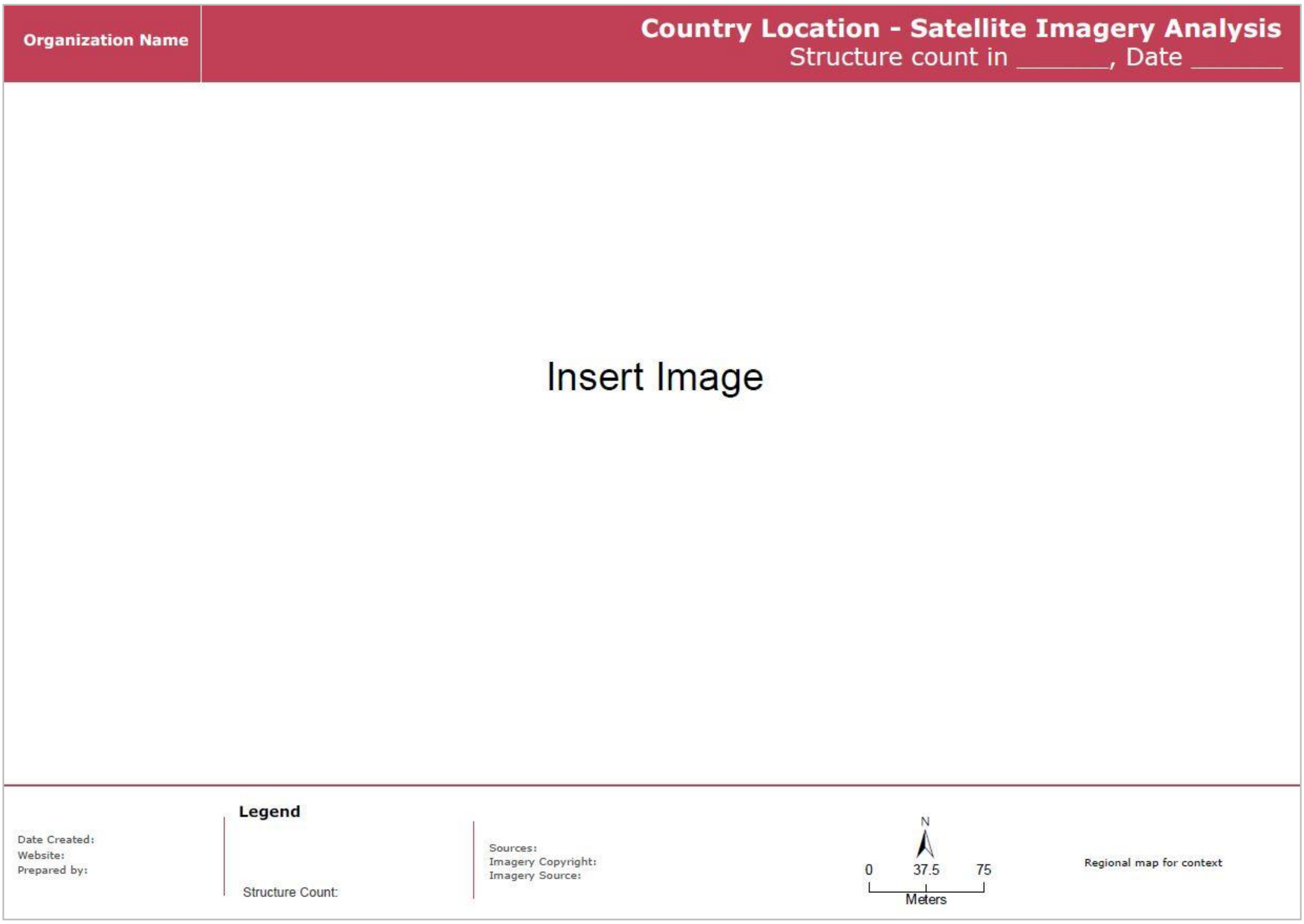
Note: this is not an exhaustive list of export types. See the QGIS website for more.

Export Type	**Process**	**Reasoning**
Map Composition	Composer >> Export as… (PDF, JPEG, SVG)	Map layouts are the best way to share information if geospatial software platforms are not accessible to others.
Project	Composer >> Save Project	If you anticipate another party to work on the project, share the entire project package. This format will maintain all map components

Shapefiles	Navigate to project folder on computer >> Select all file extensions (.prj, .dbf etc) >> Right click >> Send to >> Compressed (zipped) folder	All files associated with shapefiles must be selected and exported together. If they are not exported together, the file will not open

Appendix V: Map Template

Below you will find a suggested map template. While the presented layout is recommended, there are many ways of formatting a map. However, the elements on this map, including the title, north arrow, scale bar should be included on any map product.



APPENDIX VI: LITERATURE

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