X. Remote Sensing for Food Security Monitoring in Afghanistan

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Abstract

Two decades of war have severely weakened Afghanistan’s economy and infrastructure. Along with larger impacts on civil stability, education and health care, the current conflict in Afghanistan has resulted in widespread hunger and destitution. The 2005 National Risk and Vulnerability Assessment conducted by the United Nations found that 6.6 million Afghans do not meet their minimum food requirements and approximately 400,000 people each year are seriously affected by natural disasters, such as droughts, floods and extreme weather conditions. Given the poor security situation in the country, systems that will enable remote observations of variations of climate and their impacts on food production are critical for providing an appropriate and timely response. This chapter describes the remote sensing systems and food security analyses that the US Agency for International Development’s Famine Early Warning Systems Network (FEWS NET) conducts in Afghanistan to monitor and provide information to international donors to ensure that adequate assistance is provided during this time of development and recovery.

1 Introduction

Afghanistan has suffered over two decades of conflict. By 2008, the overthrow of the Taliban has enabled the massive influx of humanitarian and human rights personnel, along with a new government, UN sponsored foreign
peace keepers and new civil and military forces. Civil insecurity continues to be present throughout the country, caused both by remnant Taliban fighters and pro-government warlords. This insecurity has meant that organizations tasked to monitor food production and availability throughout the country are limited in their access to markets, communities and information.

The main risks to food security in Afghanistan include the following:

- Limited access to markets for remote communities
- Poor health and hygiene services
- Lack of education
- Natural disasters such as drought and flood result in loss of livelihoods
- Environmental degradation
- Ongoing political upheaval (FEWS, 2008)

The population’s progress towards reducing these risks have not moved ahead much in the past five years. According to the United Nations, currently half of the 25 million Afghans are living below the poverty line. Life expectancy at birth stands at 44.5 for men and women and the population is growing at a rate of 2.3 percent in rural areas and 4.7 percent in urban areas. Afghanistan's infant mortality rate is the highest in the world; as many as 38 percent of all newborn children do not survive beyond their first birthday. The literacy rate is one of the lowest among developing countries with only one in three Afghans over 15 able to read and write (WFP, 2008).

Hunger remains a significant problem in Afghanistan. Nearly 40% of the rural population cannot count on having sufficient food to satisfy their most basic needs. The Afghan diet, consisting mostly of grains, has little variety, creating a serious problem of malnutrition. Nearly 40% of children under 3 years old are underweight, and more than half the children in that age group are stunted (Figure 1). Both calorie intake and dietary diversity are greater for families that are closer to the market: households further from the market consume fewer calories and have a less diverse diet (Farhadi, 2005).

In this chapter we will describe the remote sensing tools used by USAID’s FEWS NET in its ongoing responsibility to monitor and report on the food security situation in the country. The Famine Early Warning Systems Network (FEWS NET) is a USAID-funded activity that collaborates with international, regional and national partners to provide timely and rigorous early warning and vulnerability information on emerging and evolving food security issues. FEWS NET professionals in Africa, Central America, Haiti, Afghanistan and the United States monitor and analyze relevant data and
Fig. 1. Estimate percent of the population who are food insecure from the National Risk and Vulnerability Assessment 2005, conducted by Government and Stakeholders from July-September 2005.

information in terms of its impacts on livelihoods and markets to identify potential threats to food security. FEWS NET uses a suite of communications and decision support products to help decision makers act to mitigate food insecurity. These products include monthly food security updates for 25 countries, regular food security outlooks, and alerts, as well as briefings and support to contingency and response planning efforts. In-depth studies in areas such as livelihoods and markets provide additional information to support analysis as well as program and policy development (FEWS, 2008).

FEWS NET and its partners have produced a variety of satellite remote sensing data products that are used to evaluate threats to food security in the region. These include data on temperature, wind, accumulated rainfall in both liquid and snow form, crop models for pastoral, rain fed and irrigated crops, and the formation and melting of the annual snow pack, which provides the majority of the irrigation water for communities in the north. This chapter will
describe the remote sensing data monitoring products and the science behind them, and how these products are used to report on the food security situation of the Afghan people.

2 FEWS NET’s Processes and Food Security Identification

In order to estimate food aid needs, FEWS NET uses remote sensing information together with social and economic data on the ways people make a living. Food aid rarely covers all the needs of its recipients, but when used appropriately, it can greatly reduce economic disruption due to climate caused production deficits (Barrett and Maxwell, 2005). USAID defines food security as follows:

When all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life (USAID, 1995).

By this definition, food security is a broad and complex concept which is determined by the interaction of a range of agro-physical, socioeconomic, and biological factors. Like the concepts of health or social welfare, there is no single, direct measure of food security.

For households dependent on agricultural production for their incomes, the shortfall in production caused by drought, flood or infestation is a good indicator of the fall in income (Callear, 1997). Because remote sensing data is inexpensive, wide in coverage and reliable, it is front and center in monitoring food security, particularly in Afghanistan with many remote and inaccessible regions. In addition to remote sensing data, FEWS NET also uses indicators of imminent crisis derived from the humanitarian community (Cuny and Hill, 1999). These include monitoring of water availability, pasture quality, livestock prices, migration patterns, school attendance, cereal prices, cereal availability, and consumption of wild foods. These indicators are used in conjunction with remote sensing to determine the overall food security situation throughout the country.

FEWS NET’s objective is to provide actionable information that motivates governments and organizations, both local and international, to pay attention to the warnings of an imminent crisis and to act in a timely manner. The information FEWS NET provides usually involves graphics that display the cause, effect, relevance, and appropriate response clearly spelled out. To do this, FEWS NET must integrate data from disparate sources at vastly different
resolutions and levels of precision. For example, an analysis of the impact of drought as measured both by vegetation anomalies and rainfall deficits needs to be integrated with information on elevated food prices (point measurements), conflict and other security problems (localized or widespread), migration patterns (usually reports from a variety of sources, but without precise geographic detail), and water scarcity (also diffuse reports) (Figure 2). To integrate these different types of information takes a great deal of work and experience by food security analysts. In Afghanistan, motivating an appropriate response is complicated by the uncertain security situation and the difficulty in delivering aid to isolated regions.

Food security terminology emerged in Afghanistan in the late 1990s and is still evolving. A comprehensive national framework for understanding food security that includes multiple indicators does not exist. Nonetheless, two indicators have been used for assessing food insecurity in Afghanistan: 1) food consumption, and 2) dietary diversity. Food consumption looks at the quantity of food eaten over a seven day period, while dietary diversity measures the quality of food eaten over a seven day period. Generally, people tend to know what they eat instead how much they eat. Therefore, FEWS NET Afghanistan

Data Input
- Physical Data (satellite-derived, gauge temperature, rainfall, vegetation density)
- Socio-economic data (nutrition indicators, livestock health, food prices)

Analysis
Integrates and analyzes physical and social conditions for a region of interest

Process
- Monthly food security reports
- Intervention guidance
- Management briefings

Policy Makers
Influences budget cycle
- Food relief
- Monetary assistance
- etc.

**Fig. 2.** Flow diagram showing the general use of biophysical data in FEWS NET and its ultimate objective, to influence the annual budget cycle to provide necessary assistance to regions in need (Brown, 2008).
chose to use the dietary diversity indicator in its analysis. The most recent dietary diversity data from the vulnerability assessment conducted in 2005 showed that 24% of the Afghan population has very poor diversity in their food consumption, including 15% of urban, 25.8% of rural, and 38.3% of nomad populations (Figure 1).

Stunting, which primarily results from lack of access to food over a long period of time, is at a very high level in Afghanistan: 2004 nutrition data indicate more than half (54 percent) of preschool age Afghan children are stunted and 36 percent underweight. Thus FEWS NET refers to food insecurity in Afghanistan as chronic, not transitory. Despite, or perhaps because of, the long term nature of the problem in Afghanistan, understanding and rapidly responding to variations in food production due to the weather is critical to alleviating crises. Addressing the long term vulnerability of the population will require development and stability which are beyond the scope and mandate of FEWS NET. Remote sensing data provides information which otherwise would be difficult to get in a timely manner due to the ongoing hostilities in the country and fragmented nature of governance.

3 Remote Sensing Products Used in Afghanistan

In collaboration with its partner USGS International Program office at EROS in Sioux Falls, and using data from NASA, NOAA and NCAR, FEWS NET has developed a variety of products used to monitor the water resources and growing conditions in Afghanistan. Table 1 describes the data products developed to support FEWS NET’s activities in the region. The following sections will describe the products which are monitored regularly in order to determine the likely outcome of the current growing season. The weather can be hazardous, both for food production but also directly. In March of 2008, for example, the three main causes of food insecurity in Afghanistan are high grain prices (40-90% higher than the four year average), the influx of Afghan workers forcibly repatriated from Iran, and a severe snow storm that caused the death of a hundred people and thousands of livestock. By integrating the biophysical with the social, political and economic, FEWS NET provides a comprehensive picture that enables decision makers to respond appropriately.
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Table 1. Satellite remote sensing products for monitoring hazards that affect food security in Afghanistan.

4 MODIS Snow Products for Afghanistan

Unlike regions in the tropics, Afghanistan has its wet season in the winter. Snow accumulates to become its primary source of water for agriculture during the summer (Figure 3). To measure how much water will be available for growing crops with irrigation water, FEWS NET monitors the rate of snow accumulation and during the spring, rate of melting. A new index from MODIS is used to estimate this snow cover extent. The automated MODIS
Fig. 3. Timeline for Afghanistan, showing when planting, harvesting and rainy season occurs throughout the year.

Snow-mapping algorithm uses satellite reflectances in MODIS bands 4 (0.545–0.565 μm) and 6 (1.628–1.652 μm) to calculate the normalized difference snow index (NDSI) (Hall et al., 1995): NDSI = band 4 / band 6. A pixel in a non-densely forested region will be mapped as snow if the NDSI is = 0.4 and reflectance in MODIS band 2 (0.841–0.876 μm) is >11%. The product is able to distinguish clouds from snow using these reflectance thresholds (Figure 4).

Snow extent products from MODIS are coupled with a model that enables an estimation of the amount of water that is present in the snow pack. Developed by Gabriel Senay at USGS EROS, the model estimates the amount of water in the snow pack. For example, if the snow covering a given area has a water equivalent of 50 centimeters (20 in), then it will melt into a pool of water 50 centimeters (20 in) deep covering the same area. This is a much more useful measurement than snow depth, as the density of cool freshly fallen snow widely varies. New snow commonly has a density of between 5% and 15% of water. Once the snow is on the ground, it will settle under its own weight (largely due to differential evaporation) until its density is approximately 30% of standing water. Increases in density above this initial compression occur primarily melting and refreezing, caused by temperatures above freezing or by direct solar radiation. By late spring, snow densities typically reach a maximum of 50% of water. This means that for every 10
Fig. 4. MODIS snow cover extent difference from previous period for March 11-21, 2008, Afghanistan based on MODIS 8-day normalized difference snow index.

inches of snow pack that accumulates, it will melt to a pool of water 5.0 inches deep (California_Government, 2008).

Scientists working for FEWS NET at USGS EROS have developed a snow water equivalent model that spatially distributes snowmelt and is driven by remotely sensed and assimilated meteorological data. The model is based upon the Utah Energy Balance (UEB) snowmelt model developed by Tarboton (Tarboton et al., 1995a). The energy balance model uses a lumped representation of the snowpack with two primary state variables, namely, water equivalence (or total amount of water, expressed in depth, in the snowpack), and energy content relative to a reference state of water in the ice phase at 0 C. This version of the model runs in a spatially distributed mode using a grid resolution of 10 km (USGS, 2008). The USGS uses a simple model that estimates energy content is used to determine average snowpack temperature, and/or fraction of the snowpack that is in liquid form. Age of the
snow surface is retained as a third state variable, used for the calculation of albedo (or reflectance properties of the surface).

The model is driven by inputs of air temperature, precipitation, wind speed, humidity, and radiation at a 6-hourly time step, a time step that is sufficient to resolve the diurnal cycle. The model uses physically-based calculations of the radiative, sensible, latent and advective heat exchanges (i.e., exchanges, or fluxes, of energy due to incoming and outgoing short- and long-wave radiation, thermal or heat conduction, evaporation and condensation, and horizontal heat transport). An equilibrium parameterization of snow surface temperature accounts for differences between snow surface temperature and average snowpack temperature, without having to introduce additional state variables. Melt outflow is a function of the liquid fraction, and is parameterized according to Darcy's law; this parameterization allows the model to account for continued outflow even when the energy balance is negative (Figure 5).

The daily rainfall input grids are derived from Rainfall Estimate (RFE) data provided by NOAA/CPC (Climate Prediction Center) (Xie and Arkin, 1997). The RFE is calculated on a 0.1-degree latitude/longitude grid. The remaining input variables required by the model (solar radiation, air temperature, wind, humidity, and atmospheric pressure) are estimated from downscaled output fields from NOAA's Global Data Assimilation System (GDAS) and the Air Force Weather Agency's MM5 (Mesoscale Model, version 5) weather forecast model.

The (daily) snow water equivalent maps show the spatial distribution of the modeled water content of the snowpack. As such, the maps also portray the spatial distribution of snow cover extent, and provide an indication of relative snow depth and water available for irrigation when the snow melts. Five years means were calculated for each day of the year based on data from the years 2003 to 2007. Anomaly maps are produced to display the absolute difference from the mean and the percent difference from the mean for each day (USGS 2008).

4.1 Snow Cover Depletion Curves

Standard snow cover depletion curves relate the percent of a basin or zone that is covered by snow to elapsed time during the snow melt season. The depletion curves help provide an indication of the temporal and spatial extent of seasonal
Fig. 5. Afghanistan snow water equivalent from March 22, 2008

Snow pack available for irrigation. A steep decrease in snow-covered area can be indicative of either shallow snow pack or high melt rates. On the other hand, a slow decrease results from either a deep snow cover or slow melt rates most likely due to low temperatures. Plotting snow cover versus degree days can help reduce this ambiguity, however these depletion curves measure the maximum extent of snow cover as a function of time without regard to air temperature.

Using hydrological basin delineation derived from the USGS HYDRO_1K Topographic Database, this analysis concentrated on watersheds upstream of important irrigation areas. An elevation threshold of 2500 meters was applied to identify areas, within each basin, where snow extent equaled approximately 100 percent of the basin area when measured using the historical March average. Monthly averages (1966 - 2001) of snow cover extent were taken from the NSIDC historical snow cover database at 25-kilometer resolution.
These monthly data are used to represent the long-term average. The short-term average was calculated based on 3 years (2001-2003) of NASA MODIS 8-day snow cover extent.

The NASA MODIS 8-day extent product, at 500-meter resolution, was used to make incremental measurements of snow cover extent above the 2500 meter zone for each basin. These data are presented for the current year (2004) and the previous year (2003). Figure 6 shows the snow depletion curves for March 2008 for a southern basin. Data only for snow above 2500m in elevation are included in the information.

5 Crop Modeling for Rain Fed and Irrigated Crops

FEWS NET uses primary rainfall products derived from local observations and satellite remote sensing products to monitor agriculture in developing countries because food production is a critical factor in food security. The United States Geological Survey’s EROS data center in Sioux Falls, South

Fig. 6. Snow water accumulation/depletion curves for an individual basin.
Dakota has been FEWS NET’s main center of expertise for the implementation of these rainfall-driven models. Although rainfall data is examined carefully every week in the context of identifying hazards, these new products have become extremely important tools to estimate food production variations from year to year.

Agricultural food production is generally estimated by the formula seen below:

\[
\text{Production} = \text{Area Cropped} \times \text{Yield} \tag{1}
\]

FEWS NET attempts to quantify both changes in the area planted as well as crop yield, but does not have the mandate to measure production directly. FEWS NET estimates variations in changes of yield and of the area planted, but does not produce systematic or official estimates of the amount of food produced in any one area \cite{Brown, 2008 #2608}.

FEWS NET needs to know how variations in rainfall affect food production, but this may not be straightforward. Two seasons with exactly the same total amount of rain may produce very different crop yields due to differences in rainfall distribution throughout the season. To move observations and merged gauge-satellite rainfall products closer to the information needed for food production estimates, FEWS NET has implemented operational measures of the impact of rainfall on specific crops through the Water Requirement Satisfaction Index (WRSI).

### 5.1 Water Requirements Satisfaction Index (WRSI) Model

FAO studies have shown that rainfall can be related to crop production using a linear yield reduction function specific to a crop \cite{Doorenbos and Pruitt, 1977, Frere and Popov, 1979, Frere and Popov, 1986}. More recently, Verdin and Klaver \cite{2002} and Senay and Verdin \cite{2001} demonstrated a regional implementation of this linear approach in a grid cell based modeling environment using the RFE2 product. The spatially explicit water requirement satisfaction index (WRSI) is an indicator of crop performance based on the availability of water to the crop during a growing season \cite{Verdin and Klaver, 2002, Senay and Verdin, 2003}. Specifically, WRSI measures the reduction in yield per unit area due to water deficiencies at specific stages of crop development. It does not attempt to measure any other kind of yield reduction, of which there are many. FEWS NET calculates WRSI for wheat and
rangeland grasses in Afghanistan. WRSI for a season is based on the water supply and demand a crop experiences during a growing season. It is calculated as the ratio of seasonal actual evapotranspiration (AET) to the seasonal crop water requirement (WR):

\[
\text{WRSI} = \frac{\text{AET}}{\text{WR}} \times 100
\]

(2)

WR is calculated from the Penman-Monteith potential evapotranspiration (PET) using the crop coefficient (Kc) to adjust for the growth stage of the crop. AET represents the actual (as opposed to the potential) amount of water withdrawn from the soil water reservoir. Whenever the soil water content is above the maximum allowable depletion level (based on crop type), the AET will remain the same as the water requirement, i.e., no water stress. But when the soil water level is below the allowable depletion level, the AET will be lower than WR in proportion to the remaining soil water content (Senay and Verdin, 2003). When the maximum allowable depletion level is exceeded, then the plant wilts and it experiences structural damage so that it is less capable of producing grain later, thus reducing yields.

The soil water content is obtained through a simple mass balance equation where the level of soil water is monitored using the water holding capacity of the soil and the crop root depth, i.e.,

\[
\text{SW}_t = \text{SW}_{t+1} + \text{PPT}_t - \text{AET}_t
\]

(3)

where SW is soil water content, PPT is precipitation, seasonal actual evapotranspiration (AET) and t is the time step index. The soil water index is reported separately and images generated for the regions that are actively growing crops during the period.

WRSI calculation requires a start-of-season (SOS) and end-of-season time (EOS) for each modeling grid-cell. Maps of these two variables are particularly useful in defining the spatial variation of the timing of the growing season and, consequently, the crop coefficient function, which defines the crop water use pattern of crops. Maize, for example, has a very different water use pattern and sensitivity than wheat, so each has their own equations for the WRSI. The model determines the SOS using onset-of-rains based on simple precipitation accounting. The onset-of-rains is determined using a threshold amount and distribution of rainfall received in three consecutive dekads. The start of season is established when there is at least 25 mm of rainfall in one
ten-day period (known as a dekad) followed by a total of at least 20 mm of rainfall in the next two consecutive dekads. The length of growing period (LGP) for each pixel is determined by the persistence, on average, above a threshold value of a climatological ratio between rainfall and potential evapotranspiration. Thus, the end of season period is obtained by adding the length to the start of season dekad for each grid cell. The WRSI model is capable of simulating different crop types whose seasonal water use pattern has been published in the form of a crop coefficient in the literature. In Afghanistan, the area cultivated in wheat is fairly small, but the information in the WRSI for the country is still very valuable for estimating deficits due to weather (Figure 7).

5.2 Irrigated Agricultural areas

The WRSI model measures the supply of moisture to a crop compared to the demand for water through evapotranspiration. In an irrigated field, the supply is derived from ground sources which are very hard to estimate at a fine resolution. Irrigated as well as rain fed crops in Afghanistan are important to overall food production, with 85% of the population dependent on the agriculture sector for their livelihood (Table 2).

Fig. 7. Wheat WRSI for Afghanistan, March 21-30, 2008.
Table 2. Agricultural statistics for Wheat in Afghanistan for two decades, from the UN Food and Agriculture Organization. Notice that increasing population is not matched by increasing land in production, yields or harvests.

To monitor variations in production due to differences from year to year in water availability, FEWS NET has developed a product called the ‘Seasonal irrigation supply and demand’. It is produced for 18 watersheds in Afghanistan derived from the GTOPO30 1-km Digital Elevation Model (DEM) using a watershed delineation tool (Figure 8). The basic demand calculation is based on irrigated winter wheat water requirements. Watershed-based volumetric water needs or water demand for the period between first dekad of November and first dekad of July are estimated based on winter wheat irrigated area estimates derived from early 1990s Landsat data. While the spatial distribution of the irrigated area was determined from the Landsat data, an area-magnitude correction was applied based on the 2001/02 irrigated area estimate conducted by FAO. The crop water use pattern is based on FAO’s crop coefficients for winter wheat with comparable agroclimatic condition in the region (Senay et al., 2007).

In a given watershed, the total (seasonal) volumetric water supply is determined by accumulating temporally and spatially the total rainfall estimate (snowfall and rain) for the period between first dekad of October and first dekad of July. Satellite-derived NOAA Rainfall Estimate (RFE) data (Xie and Arkin, 1997) is used from the first dekad of October to the most recent dekad. On the other hand, long-term average rainfall is used for the time period between the current dekad and the first dekad of July (end of season). Various
types of losses, mainly attributable to evapotranspiration and irrigation efficiency, have been estimated as multiplicative coefficients with the end result of reducing the total supply. The supply/demand ratio in percent gives a measure of the degree of correspondence between water supply and crop water demand:

\[
\text{Irrigation Supply & Demand} = \left(\frac{\text{volumetric supply}}{\text{volumetric demand}}\right) \times 100
\]

(4)

For time periods between the current dekad and the end of season, both supply and demand are estimated using climatological (1961-1990) rainfall and potential evapotranspiration from the International Water Management Institute. Although site/region specific validation is important, FEWS NET uses these anomaly maps as a semi-quantitative indicator for the correspondence between supply and demand for irrigation purposes.

Fig. 8. Irrigation Supply & Demand Anomaly (Median Year) for the period March 11-20, 2008, shows the relative magnitude of the current year seasonal irrigation supply & demand information as a percentage of the median rainfall and evapotranspiration data from IWMI during the period 1961-1990.
6 Conclusions

According to climatic records, precipitation in Afghanistan has declined for forty years. Annual precipitation averaged about 14 inches (350 mm) in Kabul in the 1960s. In the 1990s the average annual precipitation in Kabul was about 10 inches (250 mm). The resulting droughts and years of insufficient rainfall in Afghanistan have become more frequent. Small declines in precipitation and irrigation water reduce coping capacity for poor farmers who are already vulnerable due to social, political and economic upheaval due to conflict. In a country in which 85 percent of the people depend upon agriculture for at least part of their livelihood, the availability of water is crucial.

FEWS NET combines analysis of potential agricultural production variations derived from remote sensing with timing, food prices and demand in order to create a comprehensive analysis of the vulnerability to food insecurity and the need for response by decision makers. Food access in Afghanistan is more constrained than normal in 2008 for households that rely on the market due to the prevailing above average food prices. Wheat flour retail prices continue to rise, particularly in southern markets where Pakistan is the primary source of flour supplies because Pakistan has imposed restrictions on flour exportation. Additional pressure on flour prices is due to the increase in the international price of wheat, which is the result of a number of factors, including agroclimatic conditions (drought) in key producing areas of Australia and Argentina, substitution in production from wheat to maize for biofuel processing in the United States, and increased grain and beef consumption in populous countries such as China and India as a result of high economic growth and increasing incomes per capita.

Snowfall during the 2007/08 wet season was below normal, which will significantly reduce the availability of irrigation water for pre-winter cultivation in September and October of 2008. The deficits will also cause irrigation water scarcities for spring planting in March and April, reducing prospects for the main 2008 harvest that begins in May. Rainfall from February through April is critical for rainfed crops, which are primarily grown in the north. Thus remote sensing will continue to be at the forefront of analysis and monitoring of food security situation in Afghanistan.
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