# Assessing Impacts of the 2008 Drought on Winter Wheat Production in Afghanistan Using MODIS 250m NDVI Time Series

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## Abstract

Accurate and timely assessments of winter wheat production are important elements of food security decision making for Afghanistan. Approximately 80 percent of the country's wheat production is supplied by irrigated winter wheat that relies heavily on spring snowmelt. The 2007-08 winter wheat season was characterized by a below average snowpack, abnormally high spring temperatures, early snowmelt, and poor rainfall, which created drought conditions throughout most of the country. Famine Early Warning Systems Network (FEWS NET) scientists at the U.S. Geological Survey Earth Resources Observation and Science (EROS) Center assessed how drought conditions impacted the 2008 winter wheat season and were able to frame the severity of the drought in the context of recent history as a guide to decision making. We used MODIS 16-day composite normalized difference vegetation index (NDVI) time series and historical yield data to evaluate the 2008 wheat season in comparison to the previous 8 years. The unique phenology of the winter wheat crop allowed us to derive a metric that showed good correlation with historical yields for irrigated areas. The NDVI data were temporally smoothed to eliminate cloud contamination, masked to isolate irrigated agricultural areas, and spatially averaged at the province level. We correlated annual maximum NDVI values for each province with yield statistics at both the national level and an aggregation of Northern provinces, which supply the majority of the country's wheat production. Yield statistics were from Crop and Food Supply Assessment Missions (CFSAMs) supported by the Food and Agriculture Organization and the World Food Program from 2000 to 2007. The results showed good correlations for the national level ($R^2 = 0.92$) and the Northern provinces ($R^2 = 0.76$). We used this relationship with annual maximum NDVI as a basis for ranking the 2008 winter wheat yield. Results showed that the 2008 season ranks among the worst in the 9-year history for irrigated areas. These findings were further supported by using a simple thresholding of maximum NDVI as a surrogate for productive wheat area. We applied an upper threshold to the annual maximum NDVI at each pixel to create maps of productive wheat area and compared interannual variability at the province level. The 2008 season was clearly shown to be less productive than other years in the time series, with large interannual variability in productive wheat area between provinces.

## Background of the 2007-08 Wheat Season in Afghanistan

Things we know:

- Below normal snowpack (both extent and water volume).
- Abnormally high spring temperatures, resulting in early snowmelt
- Below normal rainfall during the Spring

Unknowns:

- How does the 2007-08 season rank in terms of previous growing seasons?
- Were irrigated wheat areas equally impacted?
- Are the differences quantifiable? If so, to what degree?

## Data Inputs

MODIS 250m normalized difference vegetation index (NDVI), 2000-2008

- Temporally smoothed (Swets et al. 1999)
- Masked for irrigated agriculture
- Spatially averaged, ranked by year, at national and provincial levels

Irrigated (and Rainfed) Agricultural Map (Figure 1)

- Food and Agricultural Organization (FAO) / United Nations Development Program/Afghan Geodesy & Cartography Head Office – Kabul

CFSAM National Yield Estimates (2000-2007)

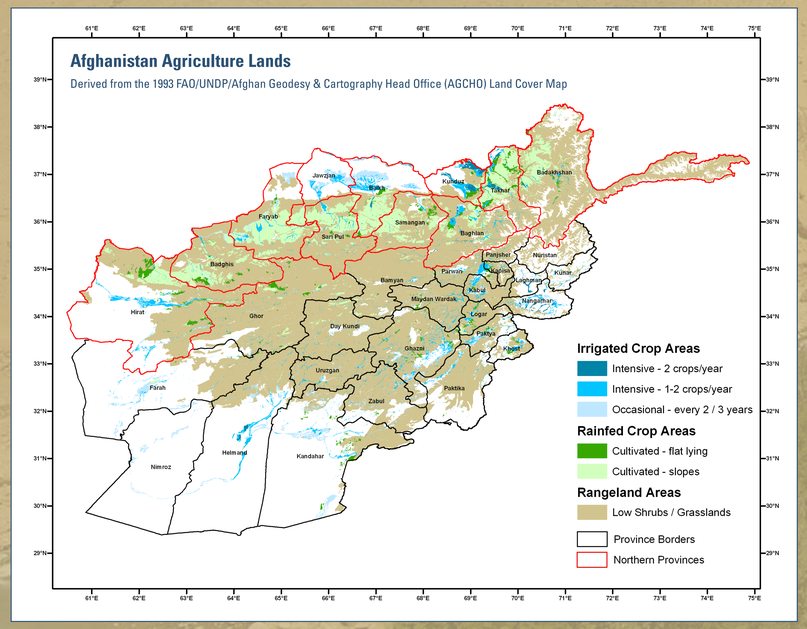


**Figure 1.** Afghanistan Agricultural Lands Map.

Background photo courtesy of Bob Bohannon.

## Wheat Yield Estimation and Maximum NDVI Ranking

### Analysis

Seasonal maximum NDVI has been shown to correlate well with winter wheat yields (USDA/FAS 2008). We used MODIS 250m 16-day NDVI time series, stratified by irrigated agricultural areas, and historical yield data to evaluate the 2008 wheat season compared to the previous 8 years. Because the majority of Afghanistan's wheat production, 75-85 percent, comes from irrigated crop areas (FAO/WFP 2004), we focused on results for irrigated lands.

MODIS NDVI time series data were assembled for the period 2000 to 2008, temporally smoothed to remove cloud and other atmospheric contamination, and then stratified by irrigated areas. The time series data were spatially averaged at the provincial level and the annual time series were analyzed to derive the time of annual maximum. The timing of maximum NDVI for winter wheat was consistently found during MODIS periods 113 and 129 (Late April - mid May). The average of these two periods was then correlated with province-level wheat yields obtained from CFSAMs and agricultural statistics for 2000 to 2007.

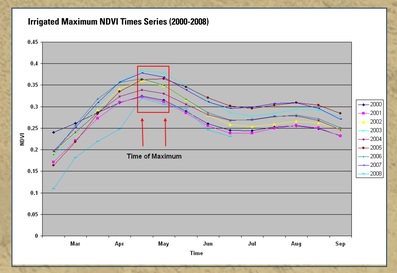


**Figure 2.** NDVI time series for national-level irrigated areas.

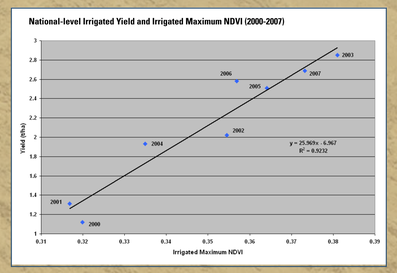


**Figure 3.** Correlation of maximum NDVI and wheat yield.

National-level NDVI time series (Figure 2) show consistent phenological patterns for each year. Figure 3 shows the correlation between these maximum NDVI values and national wheat yields. Although this is a very limited number of samples, the strong relationship gave us confidence that we could frame the current season relative to previous years and provide the timely food security information that was desperately needed.

### Results

Nationally, the 2008 maximum NDVI ranks as the worst in recent history. An estimated 1.14 tons per hectare is expected using the regression-based yield figures. This ranks as second worst yield on record and less than half the yield of the most productive year (2003). Figure 4 graphically portrays the difference in maximum NDVI between the 2008 season and the productive 2003 season.

**2008 ranks as the worst yield since 2000**

| Year | Maximum NDVI | Yield (t/ha) |
|---|---|---|
| 2003 | 0.381 | 2.85 |
| 2007 | 0.373 | 2.69 |
| 2005 | 0.364 | 2.51 |
| 2006 | 0.357 | 2.58 |
| 2002 | 0.355 | 2.02 |
| 2004 | 0.335 | 1.93 |
| 2000 | 0.320 | 1.12 |
| 2001 | 0.317 | 1.31 |
| 2008 | 0.313 | 1.14* |

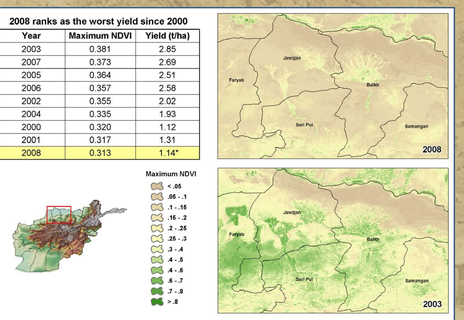


**Figure 4.** Maximum NDVI ranking and comparison to a productive year. Estimated yield (*).

Annual Maximum NDVI Ranking for Irrigated Northern Provinces

| Badakhshan | | Badghis | | Baghlan | | Balkh | | Faryab | | Hirat | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year |
| 0.39 | 2007 | 0.54 | 2003 | 0.55 | 2003 | 0.34 | 2003 | 0.64 | 2003 | 0.39 | 2003 |
| 0.38 | 2004 | 0.49 | 2002 | 0.54 | 2002 | 0.31 | 2006 | 0.50 | 2002 | 0.38 | 2007 |
| 0.37 | 2002 | 0.46 | 2007 | 0.50 | 2004 | 0.31 | 2007 | 0.43 | 2005 | 0.37 | 2005 |
| 0.36 | 2006 | 0.44 | 2005 | 0.49 | 2007 | 0.30 | 2005 | 0.41 | 2007 | 0.36 | 2002 |
| 0.36 | 2001 | 0.37 | 2004 | 0.48 | 2005 | 0.25 | 2002 | 0.37 | 2006 | 0.35 | 2006 |
| 0.36 | 2000 | 0.36 | 2006 | 0.48 | 2006 | 0.25 | 2004 | 0.36 | 2004 | 0.32 | 2004 |
| 0.36 | 2005 | 0.29 | 2008 | 0.42 | 2001 | 0.24 | 2000 | 0.26 | 2000 | 0.31 | 2008 |
| 0.34 | 2008 | 0.28 | 2000 | 0.41 | 2000 | 0.22 | 2001 | 0.24 | 2008 | 0.30 | 2001 |
| 0.34 | 2003 | 0.27 | 2001 | 0.40 | 2008 | 0.18 | 2008 | 0.20 | 2001 | 0.30 | 2000 |

| Jawzjan | | Kunduz | | Samangan | | Sari Pul | | Takhar | | Northern Provinces | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year | Max NDVI | Year |
| 0.60 | 2003 | 0.58 | 2003 | 0.47 | 2003 | 0.45 | 2003 | 0.66 | 2003 | 0.48 | 2003 |
| 0.34 | 2006 | 0.55 | 2007 | 0.44 | 2007 | 0.44 | 2002 | 0.55 | 2002 | 0.43 | 2007 |
| 0.33 | 2005 | 0.50 | 2005 | 0.43 | 2004 | 0.42 | 2007 | 0.53 | 2007 | 0.43 | 2002 |
| 0.31 | 2007 | 0.50 | 2002 | 0.42 | 2005 | 0.42 | 2005 | 0.51 | 2005 | 0.41 | 2005 |
| 0.31 | 2002 | 0.49 | 2006 | 0.39 | 2002 | 0.40 | 2006 | 0.51 | 2006 | 0.40 | 2006 |
| 0.23 | 2004 | 0.48 | 2004 | 0.38 | 2006 | 0.39 | 2004 | 0.50 | 2004 | 0.38 | 2004 |
| 0.22 | 2000 | 0.46 | 2001 | 0.36 | 2001 | 0.35 | 2000 | 0.46 | 2001 | 0.33 | 2000 |
| 0.21 | 2008 | 0.45 | 2000 | 0.35 | 2000 | 0.35 | 2001 | 0.46 | 2008 | 0.32 | 2001 |
| 0.17 | 2001 | 0.42 | 2008 | 0.29 | 2008 | 0.32 | 2008 | 0.45 | 2000 | 0.32 | 2008 |

**Figure 5.** Maximum NDVI ranking for irrigated agriculture in the eleven northern provinces.

The majority of Afghanistan's production comes from the northern irrigated provinces shown in Figure 1, making these of particular interest to the food security community. A ranking of provincial results for the north showed a situation similar to that at the national level. When taken in aggregate, 2008 ranks as the worst year on record for the Northern provinces as well.

## Irrigated Wheat Productivity Assessment

### Analysis

A secondary analysis was done to estimate differences in the amount of productive area throughout the 9-year time period to evaluate how it may vary through both time and space. Seven Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) visible near-infrared scenes were acquired for the time of maximum NDVI (April-May). The ASTER imagery was used as a guide to identify an NDVI productivity threshold that could be applied to the 2000-2008 series and to 'validate' the NDVI magnitude differences with higher resolution data. MODIS 250m NDVI was very effective at capturing the spatial variability.

**ASTER 15m VNIR - May 15, 2007** | **NDVI Maximum w/0.35 threshold - May 2007**

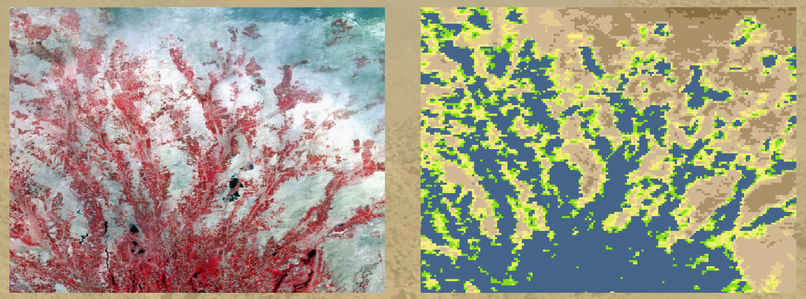

**Figure 6.** ASTER image and maximum NDVI with productivity threshold (blue) for an area in Balkh province.

Thresholded values of > 0.35 maximum NDVI showed good spatial agreement with the productive areas identified using the ASTER scenes. Productive area measurements were calculated for irrigated areas within each province areas and summarized for each year.

### Results

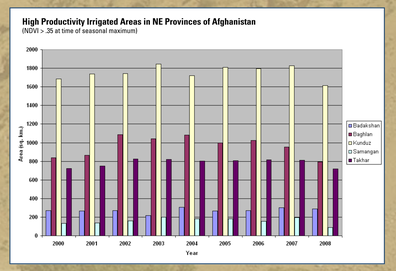


**Figure 7.** Productive area estimates for provinces in Northeastern Afghanistan.

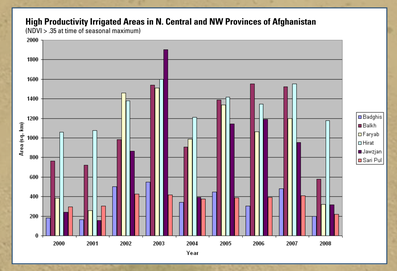


**Figure 8.** Productive area estimates for provinces in North Central and Northwestern Afghanistan.

The productive area estimates for irrigated areas varied regionally across the northern provinces of Afghanistan. The Northeastern provinces showed fairly consistent productive area estimates from year to year (Figure 7). The North Central and Northwestern provinces showed a high degree of interannual variability (Figure 8). For irrigated agriculture it stands to reason that the North Central and Northwestern provinces would be more susceptible to variability in available irrigation water from snowmelt. These areas have thinner snowpack and are subject to greater interannual temperature differences in early spring, whereas the Northeastern provinces are at higher elevation and maintain snowpack, and thus water for irrigation, much later in the year.

## Conclusions

Analysis of the irrigated winter wheat crop shows that 2008 ranks among the worst years in the series, on par with 2000. While this analysis focused on irrigated winter wheat, the findings strongly suggest failure of the rainfed winter wheat crop as well. Irrigated productive areas varied by region and further illustrated the poor conditions in 2008. These methods provide a very quantifiable procedure for assessing relative crop performance using the relationship of maximum NDVI and yield statistics. This analysis provided timely information that had an enormous impact on food security decisions being made for the country of Afghanistan. The United States Agency for International Development FEWS NET program manager acknowledged that this analysis influenced the USDA's Afghanistan harvest forecast and became the official US view. It was also noted that this collaboration helped to forge a new and stronger relationship with USDA for making production estimates.

## References

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