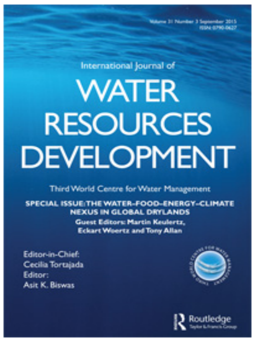


**International Journal of Water Resources Development**

ISSN: 0790-0627 (Print) 1360-0648 (Online) Journal homepage: www.tandfonline.com/journals/cijw20

# Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin

**Hadi H. Jaafar, Rami Zurayk, Caroline King, Farah Ahmad & Rami Al-Outa**

**To cite this article:** Hadi H. Jaafar, Rami Zurayk, Caroline King, Farah Ahmad & Rami Al-Outa (2015) Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin, International Journal of Water Resources Development, 31:3, 436-449, DOI: 10.1080/07900627.2015.1023892

**To link to this article:** https://doi.org/10.1080/07900627.2015.1023892

*International Journal of Water Resources Development*, 2015
Vol. 31, No. 3, 436–449, http://dx.doi.org/10.1080/07900627.2015.1023892

Routledge
Taylor & Francis Group

# Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin

Hadi H. Jaafar[a]*, Rami Zurayk[b], Caroline King[c], Farah Ahmad[d] and Rami Al-Outa[d]

[a]*Department of Agriculture, Faculty of Agricultural and Food Sciences, American University of Beirut, Lebanon;* [b]*Department of Landscape and Ecosystem Management, Faculty of Agricultural and Food Sciences, American University of Beirut, Lebanon;* [c]*School of Geography and the Environment, Oxford University Centre for the Environment, UK;* [d]*Department of Agriculture and Department of Landscape and Ecosystem Management, Faculty of Agricultural and Food Sciences, American University of Beirut, Lebanon*

(*Received 15 December 2014; accepted 24 February 2015*)

The impact of conflict on irrigated agriculture and consequently summer crop production within conflict-affected agricultural lands was observed in the Orontes Basin. Water and energy use were reconfigured through a transition from rainfed to irrigated agricultural production over the past 20 years, but have been disrupted as the Syrian war has unfolded since 2011. Remotely sensed vegetation indices were used to determine irrigated summer crop yields during the year 2013. Findings suggest that irrigated agricultural production dropped between 15% and 30% in the Syrian portion of the basin in 2000–2013, with hotspots identifiable in Idleb, Homs, Hama, Daraa and Aleppo. The developed approach demonstrated effectiveness in quantifying and geolocating hotspots where conflicts have the strongest impact on agricultural water use, agricultural production, and eventually support relief and regional agricultural reconstruction in this and other conflict regions.

**Keywords:** Syria; Orontes Basin; conflict; food security; irrigated agriculture; vegetation index

## Introduction

Remote sensing can provide a prompt and relatively accurate assessment of agricultural water use and productivity in conflict zones, providing insights on the food security status of the affected communities. Considerable efforts have been spent in developing agricultural and crop yield change methods using remotely sensed data (see e.g. Basso, Cammarano, & Carfagna, 2013). While remote sensing and satellite imagery uses for civil and agricultural applications have recently increased, there are fewer instances in which satellite imagery has been used to study the effects of war on changing human and natural landscapes and food security. Examples include imagery-based crisis identification used by various agencies, including the UN and non-governmental agencies (Marx & Goward, 2013; Marx & Loboda, 2013), for assessment of violation of human rights. Other examples include observation of villages in Sudan destroyed by war (HIU, 2004) and conflict-led rural abandonment of agricultural lands in the two-year war in Kosovo (Terres, Biard, & Darras, 1999), and Bosnia (Witmer, 2008) and Darfur using MODIS (Moderate Resolution Imaging Spectroradiometer) imagery and SPOT (Satellite Pour l'Observation de la Terre) imagery.

*Corresponding author. Email: hj01@aub.edu.lb

This investigation focuses on the Orontes Basin, an international river basin shared by Lebanon (8%), Syria (56%) and Turkey (36%) (Wolf, Natharius, Danielson, Ward, & Pender, 1999). Over the past 20 years, this basin has undergone a transition from rainfed to irrigated crop production. The resulting changes in patterns of water and energy use for food production were particularly rapid in Syria. The percentage of irrigated agriculture in Syria increased from 28.55% to 44% (from 1 million to 1.5 million ha) from 1994 to 2004, although the total farmed area dropped by 13% (from 3.8 million to 3.3 million ha).

The evolving regional dynamic of the water–food–energy nexus changed rapidly with the outbreak of war in Syria in March 2011. By mid-2014, it had led to the displacement of more than six million Syrians. The majority of the displaced population were rural and depended on agriculture for their livelihood. Since the onset of the war, agricultural production in Syria has dropped severely, with millions in rural areas requiring emergency assistance and support. With the possible exception of the coastal areas, most of Syria's rural areas were significantly affected. News reports from the Food and Agriculture Organization of the United Nations have suggest that agricultural production has been halved in some areas (FAO, 2013)

Due to the security problems and the difficulty and the high risk involved when entering the affected areas, little research has been done to quantify the effect of the conflict on agricultural production and water use within Syria. Jaubert, Munger, and Bosch (2014) conducted fieldwork in the Qusair region in Homs and report a decline of production of 70% attributed to conflict. From early 2014, government and rebel forces are each believed to have controlled about 40% of the basin, while the remaining 20% were combat zones (Jaubert et al., 2014). This makes both sides equally capable of implementing a scorched-earth policy by cutting the flow of the irrigation water. It must be noted, however, that just 37% of the irrigated land in Homs and 10% in Hama uses water from government irrigation projects where the flow can be controlled (Table 1); over 60% of the water originates from individual wells which cannot be controlled by the state forces. These data were confirmed by the fieldwork of Jaubert et al. (2014, p. 18) specifically for the Qusair region.

Remote-sensing analysis of satellite imagery and other remotely acquired data offers a safe and promising tool that can aid in observation and quantification of changes in agricultural water management and support preparedness for emergency response activities. Available satellite sensors provide a means for the indirect assessment of agricultural changes via estimates of actual evapotranspiration (ET), Net Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and other indices. These

Table 1. Irrigated areas (in ha) according to sources of irrigation water in studied regions.

| | Irrigated lands (ha) | | | |
|---|---|---|---|---|
| | Pressurized irrigation | Irrigation by gravity | | |
| Governorate | Rivers and springs | Government irrigation projects | Wells | Total irrigated land |
| Homs | 9,457 | 19,902 | 25,878 | 53,857 |
| Hama | 5,576 | 6,863 | 56,871 | 69,044 |
| Idleb | 4,490 | 7,396 | 43,489 | 54,951 |
| Quneitra | 590 | 1,389 | 2,528 | 4,331 |
| Aleppo | 37,075 | 60,726 | 98,175 | 193,059 |
| Daraa | 4,127 | 18,107 | 12,813 | 31,318 |
| Rural Damascus | 17,363 | 4,207 | 48,477 | 66,106 |

sensors collect data at a coarse resolution (250 m to 1 km) and may not accurately reflect the ground situation, especially for small agricultural clusters.

With the presence of high-resolution satellite sensors such as Geo-eye, WorldView 1 and 2, IKONOS and QuickBird, satellite image data available at various spatial, spectral and temporal resolutions allow agriculture and crop assessment. Parameters include crop health, change detection, environmental analysis, irrigated landscape mapping, yield determination and soils analysis. The major constraint regarding analysis using imagery from such sensors is the high cost associated with the imagery (prices can reach $38/km$^2$ for tasking, with minimum orders of 25 km$^2$ per area of interest). Another constraint is the huge amount of computer storage and memory required for analysis of these images. The purpose of the research is the development of a GIS-based crop yield model based on vegetation indices derived from freely available remote-sensing data as a support tool for parties engaged in planning for humanitarian response. Such a model would be important not only for use in times of war but also for reducing the impacts of natural disasters such as recurring droughts.

The model provides quantitative data on the production of irrigated summer crops in the Orontes Basin of Syria, one of its main agricultural regions but currently at the centre of ongoing military activities.

This could support preparedness and mitigation interventions to enhance the resilience of rural communities. It will also help delineate zones in need of emergency relief.

## Methodology

### *Study area background and scene selection*

In April 2011, Syrian anti-government protests slowly turned into an armed civil conflict between the Syrian army and anti-government forces. By January 2014, the war had caused the death of more than 130,000, the displacement more than 6 million Syrians and severe damage to the economy and infrastructure of Syria. Estimates for damages to the agricultural sector are more than $1.8 billion. Syrian agricultural production is reported to be dropping as conflict continues, with wheat and barley production showing a 55% drop, vegetables 60%, and fruit trees and olive oil production 40% (FAO, 2013). Aside from the widespread lack of security in most governorates, Syrian agriculture in the last three years has suffered from increased fuel costs, destroyed and looted machinery, transportation problems and destruction of irrigation infrastructure. There are also reported cases of decrease in harvested lands. Agricultural trade has also been affected by sanctions.

The studied areas lie in parts of the Orontes River basin in western Syria and in north-eastern Lebanon (Landsat Scene Path 174 Row 036). Three studied regions are near the cities of Homs and Qusair (home to major field battles in May 2013); one is north of Hama (home to a major conflict in spring of 2012).

Additional regions in Lebanon were selected to disentangle the effect of conflict from that of other agro-ecological factors. The main comparison unit is in the Qaa area of Lebanon, adjacent to the Qusair region in the Homs District and part of the Orontes Basin. The Mid-North Beqaa area, falling within the Litani River basin and unaffected by the war in Syria, was added as a ‘placebo’ to address the possible interdependency of the Qaa and Qusair sites, according to the procedure for comparative analysis of small-*n* samples developed by Glynn and Ichino (2014). This choice of method is supported because agricultural integration between the two areas is minimal. Production in the two regions aims at different markets, one essentially Syrian and the other Lebanese. Some minimal overlap could have taken place before 2011 as inputs were smuggled from Syria to Lebanon (essentially subsidized diesel). The only possible effect is the overflow of labour from Syria to El Qaa, but this is a common phenomenon, dating back to the mid-twentieth century, as Lebanon has always been the main destination for Syrian seasonal migrant labour and labour shortages were never experienced.

The long-term production records for El Qaa are stable, indicating no effect of the war in Syria on agricultural production. The long-term records for adjacent Qusair show a dip during the period of study. The only difference is the active conflict in Qusair. According to John Stuart Mill's method of difference (quoted in Glynn & Ichino, 2014, p. 5):

> If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance save one in common, that one occurring only in the former; the circumstance in which alone the two instances differ, is the effect, or cause, or a necessary part of the cause, of the phenomenon.

If one agrees with the principle that a regional state of war is different from an active conflict, and that the two locations are otherwise similar (in agro-climatic conditions), then this directly implies that the conflict is the cause of the observed difference in crop yields between El Qaa and Qusair.

Figure 1 shows the studied areas for the assessed Landsat scenes. The study area for the MODIS NDVI, EVI and Drought Severity Index (DVI) data is the irrigated zones within the country of Syria. All the study areas are distinctively agricultural. All areas rely on irrigation for agricultural production, because the summer growing period (June–August) is characterized by zero effective rainfall. Evaporation in April and May is high enough to deplete the winter residual of the available soil moisture within the root zone of summer crops. The Orontes River and associated springs and irrigation projects are the major source of water for these areas. The areas are analyzed for recent marked changes in atmospherically corrected reflectance from the red and near-infrared bands of the acquired Landsat imagery.

The locations of the study areas were selected based on the following rationale:

(1) The areas are heavily farmed, cropped and irrigated during normal years from storage reservoirs and from the Orontes River. Field battles amongst the conflicting forces had occurred in the Syrian territories and are reported to have disrupted farming activities in those areas. The selected Lebanese areas were not directly affected by major Syrian conflict during the analyzed period (2000–2013), allowing us to consider these areas as comparative units (with the exception of the Qaa region).
(2) The area on the Lebanese–Syrian border (Qaa) is contiguous with the Qusair Area in the Syrian territories, the examination of which will determine whether there was an impact of the Syrian crisis on agricultural activities in that zone.
(3) The study areas lie in the same climatic zone (arid to semi-arid), with similar topographic, vegetative and crop-type characteristics.
(4) The 'placebo' area was delineated based on the existence of agricultural lands within the same Landsat scene, to preserve the temporal resolution of the analysis.
(5) The climate of the region is arid to semi-arid. Annual average precipitation ranges from 200 to 600 mm/y. The wet season starts in October and ends in April. During the dry season, the eastern part of the selected Landsat scene (inland) is mostly cloud-free. The western part (mostly mountains and coastal area) sometimes has significant cloud cover.

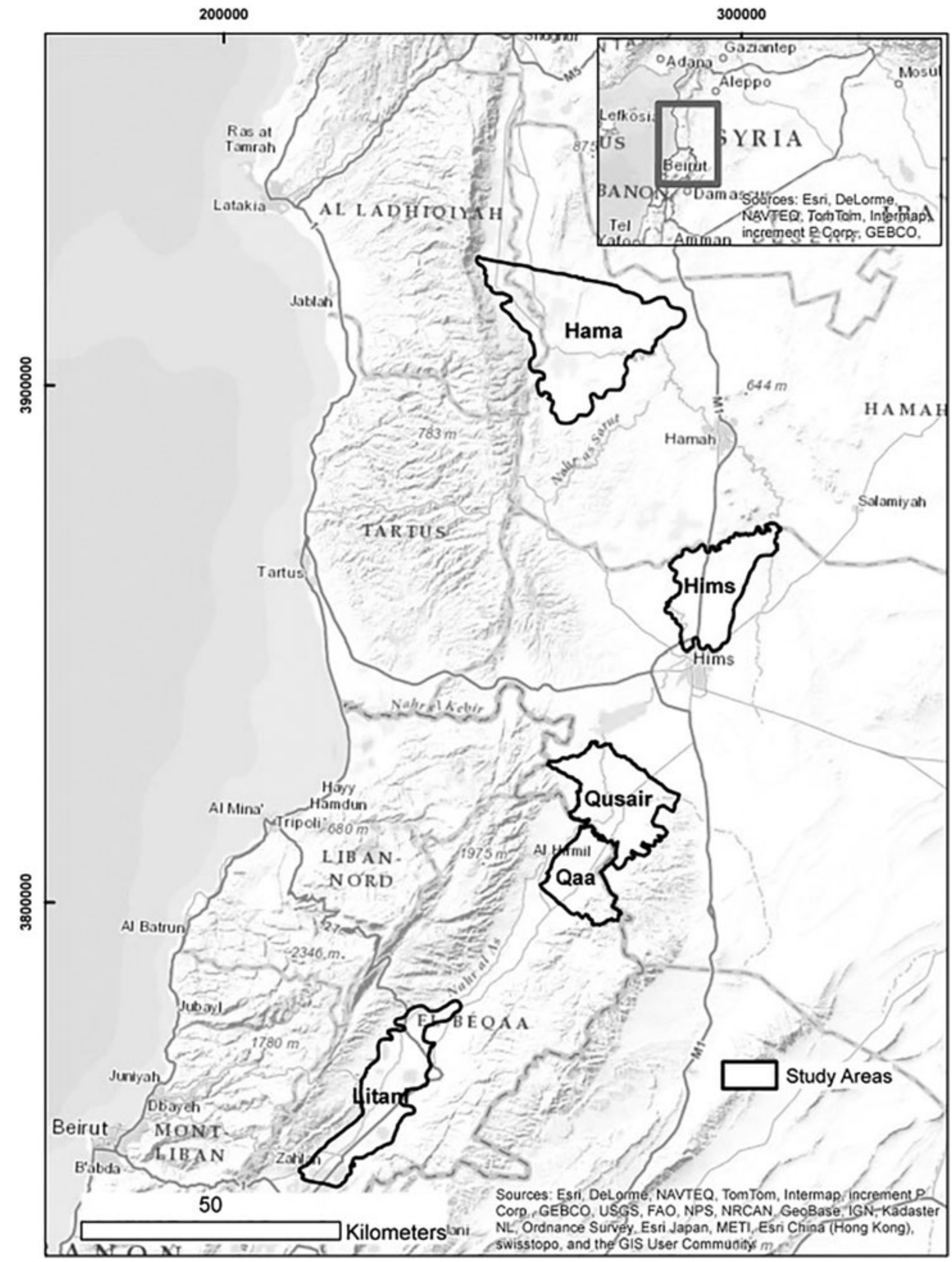


Figure 1. Pilot study areas for the fraction of vegetation analysis.

Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM + ) and Landsat 8 Operational Land Imager (OLI) scenes of the last 10 years were analyzed for fraction of vegetation cover (FOV) as derived from the NDVI. The input data from the developed model include the red and near-infrared bands of the Landsat scene.

### Scenes and data processing

A model using remote sensing and GIS was developed to assess the impact of the conflict on irrigated agricultural production using zonal statistics of NDVI, and the land cover change from freely available Landsat imagery (30 m resolution, see Table A1 in the online supplemental data at http://dx.doi.org/10.1080/07900627.2015.1023892).

Satellite-derived ET (Mu, Zhao, & Running, 2011) and the MODIS EVI were also used to quantify effects on agricultural water use and summer agricultural production (after Doraiswamy et al., 2005). Statistical analysis was conducted to detect the significance of changes in these metrics. The model was validated by comparing its output to production data from the pre-war years. The DSI (Mu, Zhao, Kimball, McDowell, & Running, 2013) was used to separate the effect of drought from the impact of conflict through comparison with areas in the same climatic zone in neighbouring Lebanon.

Landsat images from various sensors were collected for the summer season of years 2000–2011 and 2013. A total of 41 Landsat scenes were analyzed (May 2000 to 2013). All of the satellite images were selected to have less than 5% cloud cover and image quality better than 9 for the five study areas. When clouds covered one study area but not the other, the Landsat scene was excluded from the analysis for that area. The images detecting the change in agricultural activities are the L8 images of 2013. Depending on the Landsat mission (Landsat 5 TM, Landsat 7 ETM + or Landsat 8), three different GIS data models are developed. Landsat scenes and other remotely sensed data were downloaded from the US Geological Survey website (http://earthexplorer.usgs.gov/).

The NDVI is derived from Landsat 5 and 7 bands by converting calibrated 'digital numbers' of the scenes to absolute units of at-sensor spectral radiance, to top-of-atmosphere reflectance and then to NDVI using the metadata file and the necessary computational algorithms. To ensure the same scaling for the studied scenes, raw digital numbers of the bands are converted to at-sensor spectral radiance based on the procedure described in Chander, Markham, and Helder (2009). FOV was derived from the NDVI estimates (see Carlson, Gillies, & Schmugge, 1995; Gillies, Kustas, & Humes 1997). Zonal statistics for an area of interest, with means and standard deviations, were calculated in ArcGIS Spatial Analyst.

For Landsat 8, reflectance for Bands 4 and 5 were first calculated using the reflectance scaling coefficients provided in the product metadata file. The FOV is derived from the scaled NDVI between bare soil and full vegetation (Gillies et al., 1997). This scaling overcomes some of the limitations incurred by comparing the NDVI of different images, like atmospheric interference and variations in soil brightness and background scattering. Landsat 8 launched May 2013; a total of six Landsat scenes were analyzed (late May to August).

The derived FOV was used to calculate actual ET in 2013. FOV in 2013 was compared to FOVs in 2000–2011 to determine any statistical significance of differences. Zonal statistics for the other parameters (DSI, MODIS NDVI and EVI) were calculated. Trends in seasonal ET (2000–2012) are also presented to separate conflict effects from drought. DSI data (5 km) were analyzed for the period 2000–2011, MODIS NDVI and EVI data for the period 2000–2013. GIS processing and spatial zonal statistics were calculated, followed by statistical analysis for significance.

The main index that is indirectly derived from the red and near-infrared bands is the FOV. Although the derived relationship between the FOV and NDVI does not have a purely physical basis, it has been verified and documented in several works (Gillies et al., 1997). The stability of the NDVI index depends on several factors. The NDVI index indicates plant vigour. It usually exhibits strong seasonal dependence, mainly in late winter and early spring. In agricultural areas, NDVI sharply drops in summer. A high NDVI is related to healthy vegetation and strong plant vigour, while a low NDVI indicates stressed vegetation and low plant vigour, mainly low ET ('cold pixels').

To minimize the seasonal effect of precipitation, the main months that are compared are June, July and August. To avoid signal instability, NDVI is computed and compared from scenes taken within the same months for the period of record. The time difference between the images compared is a multiple of one year. Intra-annual local weather variability and changes in air masses can cause differences in remotely sensed NDVI that cannot be purely attributed to conflict effects. The compared images are mainly in the dry season (when irrigation is indispensable for crops). Average NDVI is computed for the study areas for the months of June, July and August. Six Landsat 8 images are used and compared to the averages of the zonal statistics of the reference years within the period of interest. In previous Landsat missions, the metadata file has parameters for the radiometric scaling necessary to convert digital numbers to radiance and then to reflectance. The bandwidth of the TM and ETM infrared band is 0.76–0.90, while that of the Landsat 8 OLI is narrower (0.85–0.88 nm). NDVI and FOV observations for agricultural fields are statistically tested using Student's t-test, two-tailed, to determine whether the observation is significantly different from the reference years studied.

The method of comparing FOV observation to the mean of its previous observations increases the sensitivity of the algorithm by eliminating differences between agricultural fields such as local land cover and the density of urban settings, which change little by little with time.

### *Drought severity index and ET*

MODIS-derived ET was derived using zonal statistics for the study areas and means where calculated for all the months from 2000 to 2012. The derived ET is the global terrestrial evapotranspiration that is determined from Global World Meteorological Observations and MODIS NDVI (Mu et al., 2011). Monthly means are derived the summer months of June, July and August, and trends are analyzed for significance for the period of study. MODIS-derived ET is used to calculate a new DSI. The DSI is calculated by summing standardized ET cell by cell with standardized NDVI, and then standardizing the sum. For a detailed analysis of the DSI algorithm see Mu et al. (2013).

### *Enhanced Vegetation Index analysis*

NDVI might be subject to errors from soil reflectance and lack of atmospheric normalization. The EVI is a modified form of NDVI that has a soil adjustment factor and some correction for the red band due to aerosol scattering in the atmosphere. EVI is used to detect changes in irrigated lands in the major agriculture-producing governorates. EVI metrics were analyzed by the following procedure. Monthly 1 km gridded MODIS EVI data were downloaded for all of Syria and Lebanon for the summer months of June–August for the years 2000–2013. Standardization was performed on a cell-by-cell basis according to the following. Let $v$ be the value of the parameter of every cell $i$ in a raster for a time period $t$. For all $i$,

$$Z(i) = \frac{\{v_{it} - \mu(v_{it})\}}{\sigma(v_{it})}$$

where $\mu(v_{it})$ is the temporal mean for the period 2000–2013 for every cell in the raster for every cell i in time period t; $\sigma$ is the temporal standard deviation for every cell in the raster for every cell i in time period t; and Z is the resulting dimensional index, in which trends and seasonality have been removed from the series. Zonal statistics were conducted on the metrics above to calculate the mean SEVI for the political units (governorates) of the study area. The means of EVI for conflict years 2012 and 2013 were statistically compared to the mean of 2000–2011 in each governorate.

Time series spatial means for irrigated zones for political units where calculated using GIS and regressed against time series of government-reported cropping data within the governorates for the last decade.

## Results

### NDVI and FOV analysis for pilot areas

Landsat-derived mean fractional vegetation cover values (FOV) for the study area in June, July and August (JJA) of 2013 were compared to the mean values for 2000–2011. A significant reduction was found in FOV as compared to the baseline mean in the Qusair area, reflecting a proportional reduction in consumptive water use. This is an indication of a net reduction in the irrigated area (−15%) and/or an increase in crop water stress. This decline was not registered for the adjacent Lebanese Qaa area or for the Litani 'placebo' zone, indicating that the most probable cause for the downtrend is the violent conflict that shook the region during the summer of 2013. These results are in agreement with those of Jaubert et al. (2014, p. 18), who report a decline in yields of 60% in Qusair during the same period. These findings are further confirmed by the mean values of MODIS-derived NDVI readings for the same dates (Table A2 in the online supplemental data), which show a decline of 15% for the Qusair region in the summer of 2013. During the same period, neither of the Lebanese regions, Qaa or Litani, showed any significant reduction. In fact, those areas exhibit an increase in FOV.

In northern Homs, FOV for June and July were significantly lower at a 90% confidence level, but not at 95%. Overall, in the summer months of 2013, FOV in the northern Homs part of the Orontes Basin was statistically equal to previous years. In Hama, 2013 values were significantly lower for the month of June, but not for the later summer months. Over the summer of 2013, mean FOV for Hama was statistically equal to previous years.

### ET and drought severity for Syria and Lebanon

The three-year moving average of summer ET anomalies for the five study areas is presented in Figure A1 (in the online supplemental data). The period 2000–2008 shows a decreasing ET trend followed by an increase in mean spatial ET anomalies after 2008. The MODIS ET has been validated via flux-tower data on several sites worldwide, and it is believed to be accurate within 25–30%. The wider range of summer anomalies calculated for the Hama region is believed to be due to the large irrigation activities and heavy summer agriculture in that zone. A decline in these activities will produce a sharp decrease in actual evapotranspiration, and a sharp decrease in actual evapotranspiration can be attributed to a decrease in irrigated areas, as compared to other zones with a lower average ET. This will cause a sharper anomaly. Spatial means for DSI are shown in Figure 2. Higher DSI indicates a 'wetter' summer. The DSI trend is very similar to the MODIS ET trend (DSI was derived from MODIS ET/potential ET and 1 km MODIS NDVI). An increased mean summer DSI is synchronous with an increased summer ET in

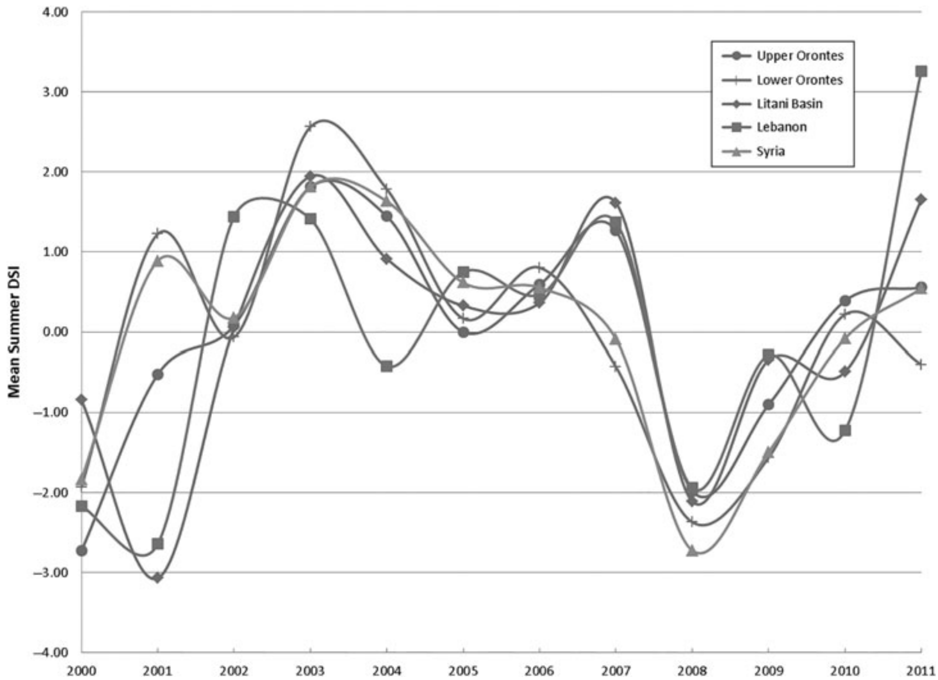


Figure 2. Spatial mean of summer Drought Severity Index for selected areas.

2008–2011. No drought trends are significant within Lebanon, Litani Basin, or Upper Orontes. The spatial DSI analysis for the 12 years for Syria and Lebanon is shown in Figure A2 (in the online supplemental data). The year 2004 is drier than average across the Eastern Mediterranean coast, while 2008, 2009 and 2010 (pre-conflict years) are drier than average within the inner arid regions. Because this drought index relies on NDVI and ET calculations, it is dependent on mainly two factors: weather and vegetation. Vegetation is affected by rainfall and agricultural activities, and the relationship between NDVI and actual ET is predictable in most cases: an increase in NDVI implies healthy vegetation, a higher leaf-area index and higher absorption of photosynthetic active radiation, causing ET to be higher for constant weather (as more green water is available for transpiration). When weather parameter values increase, ET will increase for a constant NDVI, eventually causing NDVI to decrease later in the season if water supplies are limited, hence limiting ET values afterwards.

### *EVI analysis*

EVI was calculated for the five pilot areas as well as for the summer-irrigated lands and the administrative units of Syria. Recently MODIS EVI has been used to predict crop yields, with good results (Atzberger, 2013; Potgieter, Apan, Dunn, & Hammer, 2007). The major agriculture-producing zones are the Al-Ghab Valley and the Orontes Plain. Figure A3 (in the online supplemental data) shows spatial EVI anomalies for 2012 and 2013 as compared to the mean of 2000–2011. The regions suffering from the highest EVI drop are northern Lathikiya (on the Syrian–Turkish border), the banks of the Orontes River, parts of Idleb, and Aleppo. It is noted that the same regions are affected, but the wet year of 2013 had a much lower SEVI, especially within the agricultural areas intersecting with combat zones. In 2013, areas of Damascus (Ghouta region, location of major combat in 2013), the Orontes Basin, the Turkish border at Lathikiya (another major combat zone), and the borders of Idleb and Hama are severely affected. The same areas appear to be affected when analyzing SEVI time series for the political units of Syria. Changes in agricultural lands in Quneitra (Occupied Golan Heights) and Sweida (little or no conflict) are barely noticed.

It is evident that during the years 2012–2013 there is a sharp drop in SEVI. Also, it is much more pronounced in 2013 than in 2012; this is due to the intensification of the conflict in 2013. Within the arid zones of Syria, the main vegetation cover is solely irrigated agriculture, as there is too little rainfall to sustain summer vegetation. The SEVI is particularly helpful in identifying agricultural areas, as it is these areas that suffer from stress in a variable-climate situation. To determine the relationship between EVI and agricultural production within the studied irrigated areas, summer crop yield data for the years 2000–2011 were plotted against the spatial mean of the sum of summer EVI (June, July and August) for the pre-conflict period. Regression coefficients for the relationship were determined. F-statistics were calculated to determine the significance of the trend at the 5% level.

Figure 3 shows the derived relationships between summer crop production and remotely sensed summed summer EVI for the major agricultural governorates in Syria.

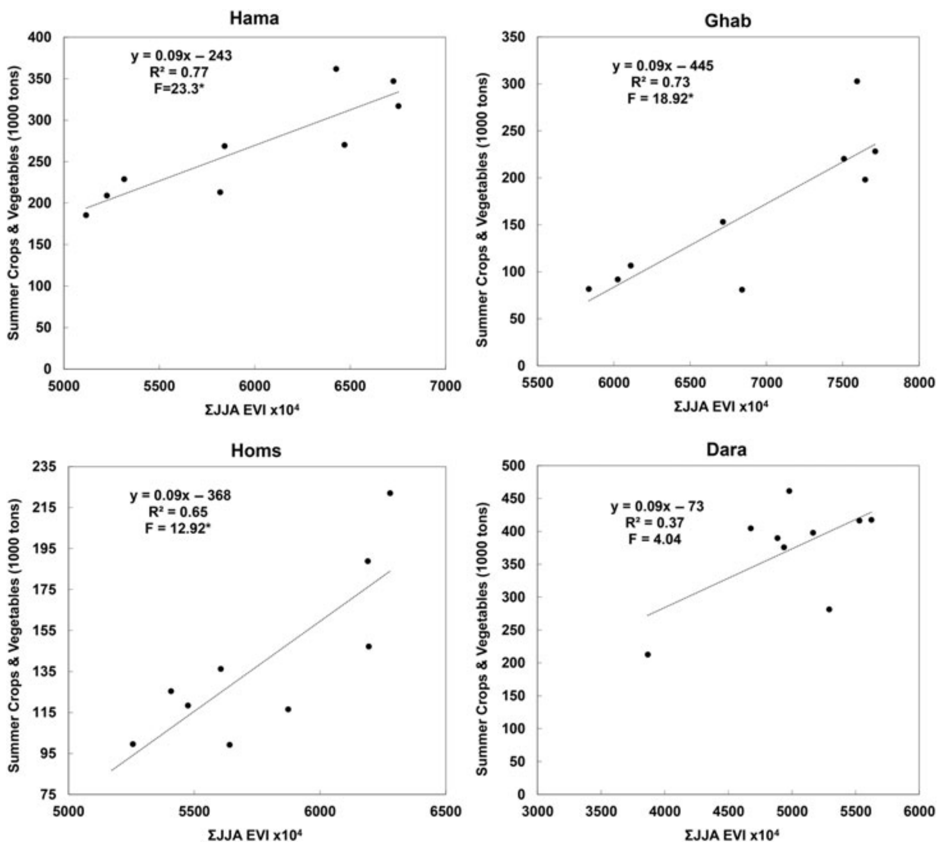


Figure 3. Relationship of summer agricultural production to cumulative summer EVI.

A significant positive linear relationship is seen in three cases (irrigated zones of Homs, Al-Ghab and Hama). The highest F-statistic is for the Hama irrigated area and Al-Ghab Valley, both lying within the Orontes River basin and both characterized by high summer production. Sum of EVI predicts production in these regions with relatively high accuracy. These relationships can be used to estimate the changes in summer production for 2012 and 2013, where crop data are not reliable (2012) or are lacking (2013). EVI mostly dropped in 2013 and 2012, as shown in Table 2. Idleb is affected most, followed by Homs, Hama, Daraa and Aleppo. Although in Idleb, Aleppo and Daraa there is a drop in EVI, there is no significant relationship between EVI and crop production in these areas. The drop in EVI more than doubled in 2013 as compared to 2012. Quantification of this drop will lead to identifying the governorates and agricultural areas that were the most affected by the conflict.

## Discussion

The investigation has achieved its aim of developing a simple, low-cost remote-sensing method for evaluating changes in the productivity of irrigated areas in specific zones without the need for 'boots on the ground'. The methodology for remotely assessing the quantitative variation in crop yields at the level of regions and basins is useful, given that the process of statistical data collection of the Syrian state, once quite solid, has been seriously hindered by the conflict and data are therefore either nonexistent or unreliable. The method was effective in identifying areas where agriculture has been adversely affected by the existing conflict.

The findings of the analysis of remotely sensed vegetation indices could provide guidance to humanitarian agencies on where emergency food aid should be focused. It will also be valuable in helping understand the relationships between decreased production, displaced rural population, and possibly shifts of labour to other sectors.

Various remotely sensed parameters related to agricultural water use and agricultural production in Syria's Orontes Basin were analyzed to evaluate the state of agricultural production as the conflict continues to unfold. The percentages of land area under irrigated vegetation cover identifiable from Landsat imagery were found to be significantly lower in 2013 than in previous years.

The indices used show a decrease in agricultural vegetation and eventually lower consumptive water use during the last decade over some parts of the Levant region. Mapping of standardized EVI demonstrate changes in vegetation within summer-irrigated lands. The spatial mean of the summer sum of EVI is highly correlated with reported yields in non-river-irrigation-dependent areas.

Conflict rather than drought is considered to have caused the reduction in agricultural productivity. The year 2013 was marked by intense battles in the area where the changes were detected. On the other hand, although a trend of increasing drought was detected for 2000–2009, this was followed by a trend of decreasing drought (2010–2012), which matches well with climatological observations. There was no significant overall drought trend.

The decline in production is not proportionally related to the decline of available water supply and/or energy for that supply. Rather, these are viewed as two of the factors affecting production. The major factor is the conflict itself, and the possibility of farmers temporarily abandoning their agricultural activities and lands for safety reasons. Identification of the specific causal mechanism(s) for the observed reduction probably cannot be done using remote-sensing methods alone, and is certainly beyond the scope of

Table 2. Changes in EVI and calculated summer crop production for the years 2012 and 2013.

| Irrigated lands | 2001–2011 mean summer sum of EVI | 2012 mean summer sum of EVI | 2013 mean summer sum of EVI | 2012 % EVI difference from mean | 2013 % EVI difference from mean | Reported mean summer production, 2000–2011 | Predicted summer production, 2012 | 2012 predicted summer production minus % difference from reported mean (2000–2011) | Predicted summer production, 2013 | 2013 predicted summer production minus % difference from reported mean (2000–2011) |
|---|---|---|---|---|---|---|---|---|---|---|
| Hama | 0.60 | 0.53 | 0.48 | −11.8 | −19.5 | 152 | 93 | −39.0 | 60 | −60.5 |
| Ghab | 0.69 | 0.60 | 0.54 | −13.6 | −21.2 | 148 | 61 | −58.7 | 25 | −83.3 |
| Homs | 0.58 | 0.52 | 0.45 | −11.4 | −22.4 | 141 | 97 | −30.7 | 39 | −72.0 |
| Idleb | 0.55 | 0.49 | 0.40 | −10.1 | −26.1 | 265 | 303 | 14.4 | 276 | 4.2* |
| Sweida | 0.31 | 0.31 | 0.29 | 0.2 | −6.5 | 51 | 50 | −1.9 | 42 | −17.2* |
| Aleppo | 0.62 | 0.62 | 0.50 | 0.9 | −19.5 | 483 | 629 | 30.2 | 662 | 37.1* |
| Daraa | 0.50 | 0.48 | 0.42 | −3.8 | −15.5 | 342 | 182 | −46.8 | 159 | −53.6* |

* Not significant at $p < .05$

this work. For insights into the mechanisms underlying the decline in crop productivity in the study area during the period of study, the reader is referred to the work of Jaubert et al. (2014) and Zurayk (2014).

## Conclusion

The article has approached the issue of irrigation and agricultural production in war-torn Syria in a new way. Remotely sensed vegetation indices over the Syrian portion of the Orontes River Basin were derived and analyzed. The research findings indicate that irrigated agricultural production dropped between 15% and 30% in the Syrian portion of the basin 2000–2013, with hotspots identifiable in Idleb, Homs, Hama, Daraa, and Aleppo regions of Syria. The remote sensing approach proved effective in identifying and locating losses in agricultural productivity due to conflict, rather than drought. However, the remote sensing tools could not be used to determine the precise causal mechanisms and dynamics taking place between the conflict and other factors, including those related to water and energy management at the local scale. Nonetheless, the effectiveness and the potential for remote sensing to be used to support relief and regional agricultural reconstruction in this and other conflict regions was demonstrated by correlating the analyzed indices to irrigated agricultural production.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This research was supported by funds from the American University of Beirut Research Board and the United States Agency for International Development under the Middle East Water and Livelihoods Initiative, managed by the International Centre for Agricultural Research in Dry Areas. The views expressed in this publication are those of the authors and do not necessarily reflect the views of funding agencies.

## Supplemental data

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/07900627.2015.1023892

## References

Atzberger, C. (2013). Advances in remote sensing of agriculture: Context description, existing operational monitoring systems and major information needs. *Remote Sensing*, *5*, 949–981. doi:10.3390/rs5020949

Basso, B., Cammarano, D., & Carfagna, E. (2013). Review of crop yield forecasting methods and early warning systems. In *Proceedings of the first meeting of the scientific advisory committee of the global strategy to improve agricultural and rural statistics*. Rome: FAO Headquarters. 18–19 July.

Carlson, T. N., Gillies, R. R., & Schmugge, T. J. (1995). An interpretation of methodologies for indirect measurement of soil water content. *Agricultural and Forest Meteorology*, *77*, 191–205. doi:10.1016/0168-1923(95)02261-U

Chander, G., Markham, B. L., & Helder, D. L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM + , and EO-1 ALI sensors. *Remote Sensing of Environment*, *113*, 893–903. doi:10.1016/j.rse.2009.01.007

Doraiswamy, P. C., Sinclair, T. R., Hollinger, S., Akhmedov, B., Stern, A., & Prueger, J. (2005). Application of MODIS derived parameters for regional crop yield assessment. *Remote Sensing of Environment*, *97*, 192–202. doi:10.1016/j.rse.2005.03.015

FAO. (2013, January 13). News article. Retrieved from Food and Agriculture Organization of the United Nations website http://www.fao.org/news/story/en/item/168676/icode/

Gillies, R. R., Kustas, W. P., Humes, K. S., et al. (1997). A verification of the 'triangle' method for obtaining surface soil water content and energy fluxes from remote measurements of the Normalized Difference Vegetation Index (NDVI) and surface e. *International Journal of Remote Sensing*, *18*, 3145–3166. doi:10.1080/014311697217026

Glynn, A., & Ichino, N. (2014). Increasing inferential leverage in the comparative method: Placebo tests in small-*n* research. *Sociological Methods & Research*. doi:0049124114528879

HIU. (2004). *Sudan (Darfur)–Chad border region confirmed damaged and destroyed villages*. Washington, DC: Department of State, Humanitarian Information Unit. (https://hiu.state.gov/Pages/Africa.aspx).

Jaubert, R., Munger, F., & Bosch, C. (2014). *Syria: The impact of the conflict on population displacement, water and agriculture in the Orontes River basin*. Geneva: Global Program, Water Initiatives Swiss Agency for Development and Cooperation.

Marx, A., & Goward, S. (2013). Remote sensing in human rights and international humanitarian law monitoring: concepts and methods. *Geographical Review*, *103*, 100–111. doi:10.1111/j.1931-0846.2013.00188.x

Marx, A., & Loboda, T. (2013). Landsat-based early warning system to detect the destruction of villages in Darfur, Sudan. *Remote Sensing of Environment*, *136*, 126–134. doi:10.1016/j.rse.2013.05.006

Mu, Q., Zhao, M., Kimball, J. S., McDowell, N. G., & Running, S. W. (2013). A remotely sensed global terrestrial drought severity index. *Bulletin of the American Meteorological Society*, *94*, 83–98. doi:doi:10.1175/BAMS-D-11-00213.1

Mu, Q., Zhao, M., & Running, S. W. (2011). Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment*, *115*, 1781–1800. doi:10.1016/j.rse.2011.02.019

Potgieter, A. B., Apan, A., Dunn, P., & Hammer, G. (2007). Estimating crop area using seasonal time series of Enhanced Vegetation Index from MODIS satellite imagery. *Australian Journal of Agricultural Research*, *58*, 316–325. doi:10.1071/AR06279

Terres, J., Biard, F., & Darras, G. (1999). *Kosovo: Assessment of changes of agricultural land use areas for the 1999 crop campaign using satellite data*. Ispra: Space Applications Institute Report, Joint Research Centre.

Witmer, F. D. W. (2008). Detecting war-induced abandoned agricultural land in northeast Bosnia using multispectral, multitemporal Landsat TM imagery. *International Journal of Remote Sensing*, *29*, 3805–3831. doi:10.1080/01431160801891879

Wolf, A. T., Natharius, J. A., Danielson, J. J., Ward, B. S., & Pender, J. K. (1999). International river basins of the world. *International Journal of Water Resources Development*, *15*, 387–427. doi:doi:10.1080/07900629948682

Zurayk, R. (2014). The fatal synergy of war and drought in the eastern Mediterranean. *Journal of Agriculture, Food Systems, and Community Development*, *4*, 9–13. http://dx.doi.org/10.5304/jafscd.2014.042.013