Meteorological, agricultural and socioeconomic drought in the Duhok Governorate, Iraqi Kurdistan

Lina Eklund · Jonathan Seaquist

Abstract   Drought is a recurrent natural hazard that is expected to increase in the future due to anthropogenic climate change. The Middle East region witnessed a drought period between 2007 and 2009 that has been reported to have severe consequences for the population, especially in Syria and Iraq. This study seeks to assess the spatial and temporal characteristics of the drought in the Duhok Governorate in northern Iraq, focusing on meteorological, agricultural and socioeconomic drought at province and village level. Satellite-based precipitation data, validated by station data, were used in a meteorological drought assessment. To estimate the decreased precipitation's effects on vegetation, an agricultural drought assessment was performed using Enhanced Vegetation Index from multi-temporal satellite data. Vegetation anomalies were studied at provincial level, and also at village level where the anomalies were compared with survey data showing the socioeconomic susceptibility to drought. The study confirms that precipitation dropped by approximately 50 %, leading to a negative anomaly in vegetation conditions for 62 % of Duhok Governorate's area in 2008. Out of 50 assessed villages, 46 experienced a negative vegetation anomaly during the drought year, and three of those experienced a strong negative anomaly. Reports of drought as a problem were frequently recorded in the exposed villages, but were also related to the level of agricultural involvement. This study emphasizes the importance of understanding drought from both physical and socioeconomic perspectives. Moreover, discrepancies in the datasets make a multi-source approach essential to avoid erroneous interpretations.

Keywords   Agriculture · Drought · Enhanced Vegetation Index (EVI) · Iraqi Kurdistan

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1 Introduction

Drought is a recurring, slow onset natural disaster that is characterized by subnormal water availability, often due to a decrease in rainfall (Belal et al. 2014; Dai 2011; Heim 2002; Wilhite and Glantz 1985). There are three general definitions of drought depending on the perspective from which it is studied: (1) meteorological—related to precipitation, (2) agricultural—related to soil moisture and crop production, and (3) hydrological—related to availability of water in rivers and aquifers (Dracup et al. 1980; Ghulam et al. 2007; Heim 2002; Panu and Sharma 2002; UNDP 2010). A fourth class, "socioeconomic drought," is sometimes used, which is defined as when water demand for an economic good is exceeding the supply, and thereby having a negative effect on people's lives (Wilhite and Glantz 1985).

Drought assessments often focus on the meteorological aspects of drought. In such assessments, precipitation data are often used to construct standardized indices in order to make them comparable over time and space (Heim 2002). The Palmer Drought Severity Index (PDSI; Palmer 1965) and the Standard Precipitation Index (SPI; McKee et al. 1993) are examples of widely used meteorological drought indices developed in the twentieth century (Bonaccorso et al. 2003; Hayes et al. 1999; Lloyd-Hughes and Saunders 2002; Tsakiris and Vangelis 2004). In countries where meteorological data are unavailable or are of insufficient quantity or quality, satellite data can be a useful method for monitoring drought. For example, vegetation greenness derived from land surface reflectance measured by satellite sensors (e.g., Normalized Difference Vegetation Index (NDVI)) can be used as an indicator for water availability in the soil, thereby representing agricultural drought (Gouveia et al. 2009; Iglesias et al. 2007; Karnieli et al. 2010; Vicente-Serrano 2007). Few drought assessments, however, include an analysis of the socioeconomic aspects of drought.

There have been at least four severe (meteorological) droughts in Iraq and its surrounding countries during the past 60 years: 1958–1961, 1969, 1998–2000 and 2007–2009 (Center for Research on the Epidemiology of Disasters (CRED) 2014; Metz 1988; Sönmez et al. 2005; Trigo et al. 2010; Zaitchik et al. 2007). Drought was last officially declared by the Government of Iraq in 2007, following a decrease in rainfall in the previous years (UNDP 2010). The drought was reported to have had severe consequences for the economy of Iraq mainly through loss of agricultural revenues (UNDP 2010). Furthermore, UNDP (2010) reported that the drought negatively impacted livelihoods, increased unemployment and induced migration of villagers "to the nearest town where water is available" (UNDP 2010).

Trigo et al. (2010) conducted a regional assessment of the 2007–2009 drought in the Fertile Crescent area, covering the countries Turkey, Syria, Jordan, Iraq and Iran. Based on precipitation data, satellite-derived vegetation proxies (NDVI) and data on lake level and agricultural productivity, they mapped the spatial and temporal extent of the drought while also evaluating the impact of this drought period on vegetation and agriculture. They found a precipitation decline of up to 70 % in Iraq during these years, with acute drought having occurred during the hydrological year 2007/2008. Furthermore, they found that the largest anomalies in vegetation condition occurred in southwestern Syria and northern Iraq with northern Iraq encountering the longest period of vegetation stress (up to 6 months) in both hydrological years. Trigo et al. (2010) provided a large scale analysis of the drought, encompassing several countries with different geographical features, but their study lacked the detail necessary to study local impact on agriculture and the rural population.

Fadhil ([2011]) conducted a study of the 2007–2009 drought in the Iraqi Kurdistan region for seven districts of the Erbil governorate. Using five satellite data-based drought indices, he found that the drought resulted in a decrease in "vegetative cover" by 56.7 % and a 29.9 % decrease in soil/vegetation wetness between 2007 and 2008. A drop of 41 % in precipitation was also noted in the hydrological year of 2007–2008, accompanied by a 32.5 % decrease in surface area of the Dokan Lake. The study was based on two Landsat satellite images taken during the dry season (June 23, 2007 and June 9, 2008) when most crops had already been harvested. The images used provided no opportunity for comparison with previous years, which may explain the extreme decrease in vegetation amount, since only 2 years were represented by single-date satellite images. A better description of vegetation anomalies would be obtained by comparing satellite imagery from multiple years acquired at different times during the season.

The overall aim of this paper is to build upon the foundation laid by Trigo et al. ([2010]) and assess the meteorological and vegetative characteristics of the drought that affected the Kurdistan Region between 2007 and 2009, together with the socioeconomic characteristics of the population in the area. Two analytical perspectives are used to provide a more comprehensive approach to drought assessment. Firstly, we assess the biophysical characteristics of the drought at the provincial level (the Duhok Governorate) using Earth observation products derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Tropical Rainfall Measuring Mission (TRMM) together with station data. Secondly, we assess drought impacts at the village level based on a large-n rural household survey conducted in the Duhok Governorate in 2011.

2 Setting

2.1 Study area

The Duhok Governorate is a province in Iraq located between 36.7°N, 42.3°E and 37.4°N, 44.2°E (Fig. 1). It consists of four districts: Amedi, Duhok, Semel and Zakho. The main city is Duhok, but each district has a capital with the same name as its district. The Duhok Governorate has an area of approximately 6,600 km^2 and had an estimated population of approximately 1.2 million people in 2009 (Kurdistan Region Statistics Office (KRSO) [2014]). It is part of the Kurdish autonomous region of Iraq that has been administered by the Kurdistan Regional Government (KRG) since 1992 (Kurdistan Regional Government (KRG) [2010]). Before 1992, there were several conflicts between the Iraqi government and the Kurdish representative parties. Such conflicts, including the *Anfal* genocide campaign of 1987–1989, led to an overall displacement of 80 % of the Kurdish population between 1961 and 1992 (Kurdistan Regional Government (KRG) [2010]; UNDP [2010]). After the fall of Saddam Hussein in 2003, the region stabilized politically and started undergoing rapid economic development.

The climate of northern Iraq (Iraqi Kurdistan) is characterized by relatively high precipitation due to the orographic heaving effect caused by the mountains (Trigo et al. [2010]). Based on 10 years' worth of data, the Duhok Governorate has an average annual precipitation of 530 mm (Fig. 2). The rainy season normally occurs between November and March, while the summer (June–September) receives little or no precipitation (Trigo et al. [2010]; Fig. 2). The growing season starts in March, peaks in May and decreases in June after the harvest of field crops (Fig. 3; Zaitchik et al. [2007]). The main rivers running through the governorate are the Khabur and the Greater Zab (UNDP [2010]).
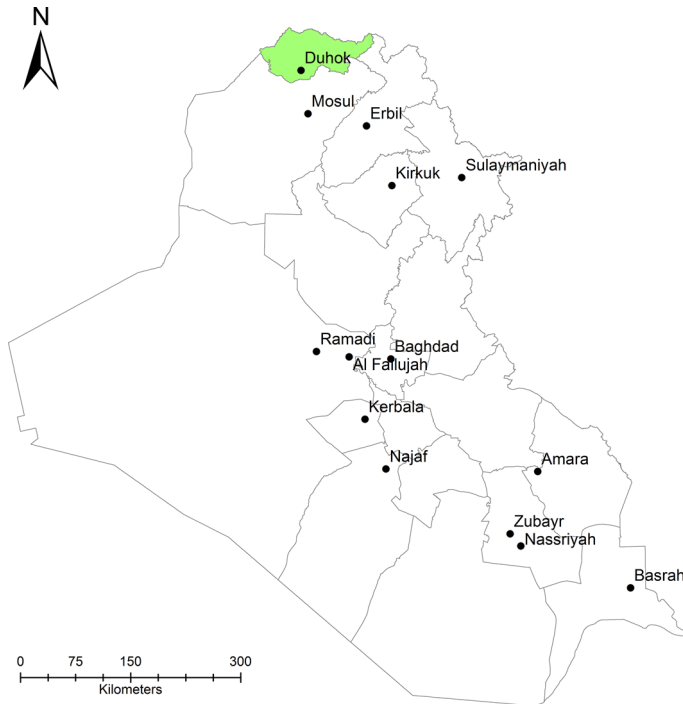
Fig. 1 Study area location in Iraq

2.2 Agriculture

During the 1980s, Iraq had one of the highest food availability per capita estimates in the Middle East (WFP Iraq—North Coordination Office 2001). Agricultural production in the three northern governorates of Kurdistan accounted for 25–30 % of all food production in Iraq, due to high soil fertility and favorable climate conditions. A major event that severely affected the food productivity was *al-Anfal* genocide campaign against the Kurds in Iraq, carried out by the Iraqi Government between 1987 and 1989, when tracts of agricultural land were destroyed, and many people were killed, imprisoned or forcibly moved (Hardi 2011; Human Rights Watch 1993; Mubareka and Ehrlich 2010). A second event that affected food production in northern Iraq was the Oil-for-Food Programme (OFF) that was implemented by the United Nations between 1997 and 2003 (Meyer and Califano 2006). During the OFF more than 2 million people were given food and medical aid, with 660,000 of them being from northern Iraq. People became dependent on food aid and ceased to rely on agriculture for food. OFF, together with lack of support in rural areas combined with droughts and instability, contributed to undermining agricultural recovery from *al-Anfal* (Hardi 2011). In a survey carried out in 2001 by the Food and Agricultural Organization, 38 % of all rural incomes in the Duhok Governorate came from agriculture, while 62 % came from non-agricultural activities (Food and Agriculture Organization of the United Nations (FAO) 2004).

Nowadays, the Kurdistan Region imports a large amount of its fruit, vegetables and poultry from nearby countries (UNDP 2010). The Kurdistan Region Statistics Office reported that in 2011, 32 % of the Duhok governorate consisted of arable land, and 15 %
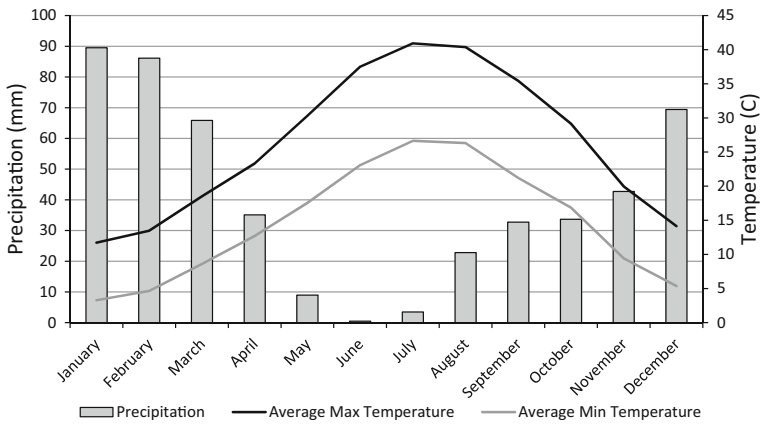
Fig. 2 Climate data based on averages of the two stations in Duhok and Zakho, and TRMM (precipitation) in the Duhok Governorate covering the period 1998–2014 (*Data source:* Directorate of Seismology and Meteorology, Duhok)

Fig. 3 Boxplot showing EVI median, quartiles, min, max and outliers for 2001–2013 in the Duhok Governorate (between 36.7°N, 42.3°E and 37.4°N, 44.2°E) based on MODIS EVI data
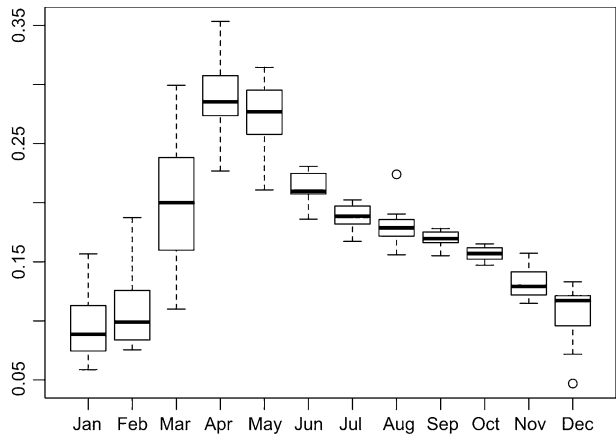
of that was irrigated (Kurdistan Region Statistics Office (KRSO) 2012). Field observations (2011–2013) show that current agriculture in the Duhok Governorate is mainly focused on cereal cultivation and that vegetable production take up only 4 % of the governorate area (Kurdistan Region Statistics Office (KRSO) 2013). Agriculture is often at a small-scale subsistence level, but the KRG is planning to develop the agricultural sector to become self-sustainable (Baban 2012).

3 Data and methods

3.1 Meteorological and agricultural drought assessment

Climate data covering 2000–2011 were obtained from the Directorate of Seismology and Meteorology in Duhok and included monthly data on precipitation (mm) and temperature

(°C) from the two weather stations located in Duhok and Zakho. In addition to the station-based precipitation data, satellite-based precipitation data from the Tropical Rainfall Measuring Mission (TRMM version 3B42 v7, 0.25° spatial resolution (Huffman et al. 2007; Kummerow et al. 1998) were added to show the temporal and spatial evolution of drought in the whole governorate. The TRMM data cover the period 1998–present and is based on precipitation radar, a microwave radiometer, and a visible and infrared scanner to calculate the properties of clouds (e.g., three dimensional structures) for obtaining quantitative rainfall measurements based on these properties (Kummerow et al. 1998). Validation of the TRMM dataset shows a relatively high agreement with precipitation gauge data in West Africa (Nicholson et al. 2003) and South America (Su et al. 2008), but shows slightly less agreement when compared with the Global Precipitation Climatology Project (Adler et al. 2000). Thiemig et al. (2012) found TRMM data to be one of the better satellite-based precipitation estimates for selected areas over the African continent. They also found that TRMM performed well in replicating the annual precipitation patterns, which makes the dataset useful for detecting anomalies. For this study, TRMM is combined and compared with gauge data to show the relative differences in precipitation, for which the accuracy is sufficient.

For the stations of Duhok and Zakho, precipitation data were plotted depicting the monthly accumulated precipitation during the wetter months (November–March) of the hydrological years (starting October 1st) 2000/2001 to 2010/2011. An average total precipitation value for this period was calculated based on the averages for each year from both stations and TRMM data. As lack of climate data (only two weather stations) combined with the low spatial resolution of the TRMM data did not provide much information on the spatial extent of the drought, these data needed to be complemented with satellite data.

For analyzing the drought's effects on vegetation (agricultural drought, see Iglesias et al. 2007; NASA Earth Observatory n.d.) while also mapping the spatial extent of the drought, data from the MODIS MOD13Q1 product were acquired through the International Research Institute for Climate and Society's Data Library (USGS: United States Geological Survey 2009). The MOD13Q1 product is composed of Enhanced Vegetation Index (EVI) estimates. The EVI is an improvement of the widely used NDVI that also uses the difference between blue and red reflectance to account for atmospheric disturbance (Eq. 1) (Solano et al. 2010);

$$EVI = G * \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + C_1 * \rho_{red} - C_2 * \rho_{blue} + L} \tag{1}$$

where, EVI, Enhanced Vegetation Index; G, gain; ρ_{NIR}, Near Infrared reflectance; ρ_{NIR}, red reflectance; C_1, 6 (coefficient for aerosol resistance); C_2, 7.5 (coefficient for aerosol resistance); L, 1 (canopy background factor).

The downloaded data have a spatial resolution of 250 m and are composited over 16 days using a constrained view angle—maximum value compositing method (CV-MVC). In this method, the two observations with the highest value are extracted and then the observation with smallest view angle is selected for the final composite (Solano et al. 2010). The composites were converted into monthly averages that covered the time period March 2001–June 2013. Yearly production proxies were then developed by summing EVI over the growing season (March–June), when most photosynthesis occurs (see Fig. 3). MODIS quality assurance images from the growing season were downloaded and analyzed to assess the influence of clouds and snow cover in the images. Images from the years showing anomalies were compared to a reference year with little anomalies.

Since drought is always measured relative to average conditions, and to facilitate comparison between different areas in the Duhok Governorate that have different vegetation amounts, EVI sums for the period 2001–2010 were converted to z scores (Hammond and McCullagh 1978);

$$z = \frac{x - \mu}{\sigma} \qquad (2)$$

where, z anomaly of growing season EVI sum, χ EVI sum for current year, μ mean of EVI sums for the period 2001–2013, σ standard deviation of EVI sums for the period 2001–2013.

The z score is a dimensionless value that represents the number of standard deviations a certain pixel's annual EVI sum falls above or below the long-term mean of the sum of growing season EVI. The long-term mean depicts normal conditions, for which a longer reference period (2001–2013) was used. The z scores were divided into five anomaly levels for visualization purposes (Table 1). "No anomaly" is defined as within one standard deviation below or above the normal value (as defined in the Standard Precipitation Index (Integrated Climate Data Center n.d.).

In order to evaluate the role that topography plays in the area, a Digital Elevation Model from the ASTER Global DEM that has a spatial resolution of 1 arc second (METI and NASA 2011) was used.

3.2 Socioeconomic assessment

A simple meteorological or biophysical perspective on drought fails to assess the negative impacts that drought has on societies, determined to a large extent by the society's susceptibility, or vulnerability, to environmental change (Wilhelmi and Wilhite 2002). Smit and Pilifosova (2003) defined vulnerability as a function of two variables: *exposure* to hazard (e.g., drought) and *adaptive capacity* of the affected community, household or individual. Exposure can be divided into three important components: frequency, longevity and spatial extent (Robards and Alessa 2004). Adaptive capacity is determined by the affected community's socioeconomic capital, i.e., economic capital and income, as well as skills and technologies, social relations, demographics and political context (Dow 1992; Robards and Alessa 2004). Drought, for example, can be mitigated by the selection of crops requiring less water, irrigation, and tillage practices (Wilhelmi and Wilhite 2002). Grothmann and Patt (2005) highlighted the perception of risks and adaptation options as important drivers of adaptation to climate change and suggested that socio-cognitive factors might better explain adaptive behavior than objective socioeconomic factors.

In order to assess the drought susceptibility of the rural population, socioeconomic and demographic data were collected in July 2011 by surveying 606 households in 51 rural villages located in the Duhok Governorate. Six local field assistants with suitable language skills (Kurdish and English) spent 10 days collecting data in 51 randomly sampled rural villages. Each day, six out of twelve villages were visited. The six extra villages had the function of "back-up" villages; in case any or all of the first six villages were inaccessible or abandoned. The villages were located using Geographical Information System (GIS) data on human settlements from the International Organization for Migration. In situ random sampling was performed within the village in order to choose the households to be interviewed. In this assessment, one village was excluded due to lack of interview data. A sample size of 50 villages out of the approximate 1100 villages located in the Duhok

Table 1 Definition of classes of vegetation anomalies based on EVI z scores

Definition (SD)	Class
More than 2	Strong positive anomaly
Between 1 and 2	Moderate positive anomaly
Between −1 and 1	No anomaly
Between −1 and −2	Moderate negative anomaly
Less than −2	Strong negative anomaly

governorate (International Organization for Migration (IOM) 2011) represents approximately 4.5 % of the whole population.

The survey included questions about household socioeconomic properties, agricultural activities, environmental difficulties faced by the household and out-migration from the village, focusing on the period between 2000 and 2010. For more detailed information on this survey, see Eklund and Pilesjö (2012). Variables used in this assessment are presented in Table 2.

Buffer zones of 2 km around each of the 50 villages were developed and overlaid with the EVI sum anomalies for each year, yielding an average EVI sum anomaly per year for each village's surroundings. The 2 km buffers were based on a normal distance usually travelled by residents to access natural resources (Fisher et al. 2012; Giannecchini et al. 2007; Leyk et al. 2012).

A Spearman correlation analysis was performed on the villages' EVI anomalies during the worst drought year and the household survey variables (Table 2). The purpose of the correlation analysis was to assess whether villages, where many households reported to be affected by drought, were associated with a stronger negative EVI anomaly, whether they had a higher involvement in agriculture, and finally estimate the role of irrigation in mitigating the effect of the drought on vegetation.

In order to gauge the range of responses across extremes the three most and the three least affected villages during the worst drought year (based on the EVI anomaly) were chosen for a more detailed descriptive analysis of socioeconomic characteristics. Furthermore, three villages in between these two extremes, i.e., median, were included to represent villages experiencing the "middle" ground. To protect the identity of households participating in the survey, the villages were assigned numerical identifiers instead of names. Villages A1–3 were the most affected (in descending order); villages B1–3 were moderately affected (based on the median) villages; and finally village C1–3 were the least affected.

A visual interpretation based on Quickbird (2.4 m), Worldview (1.84 m) and SPOT (2.5–10 m) data from 2002 to 2014 through Google Earth, using the OpenLayers plugin (Sourcepole 2013) in QGIS (QGIS Development Team 2014) was conducted in order to see what type of agricultural land cover were affected by drought. Similar approaches have been used by Alcantara et al. (2012), Baumann et al. (2012) and Clark et al. (2010).

As reported by UNDP (2010), migration to cities was one of the responses to drought. Consequently, survey data on migration were included in the descriptive analysis. Data on migration from the villages reported by each household were averaged for each village and compared between the worst and least affected villages.

Table 2 Survey data variables used in this assessment

Variable	Description
Reported drought[a]	The percent of households in the each village reporting drought as a problem
Reported frost and cold temperatures	The percent of households in the each village reporting frost and cold temperatures as a problem
Agricultural activity[a]	The percent of households in each village reporting to be cultivating land
Agricultural income[a]	The percent of households in the each village reporting agriculture as a major income
Irrigation[a]	The percent of the village's household's agricultural land that is reported to be irrigated
Migration since 2006[a]	An average of the number of households reported to have migrated from the village since 2006

[a] Used in correlation analysis

4 Results

4.1 Meteorological and agricultural drought

The TRMM data measured a decline in rainy season rainfall during the two hydrological years between 2007 and 2009, which was validated by the station data (Fig. 4). During the hydrological year 2007/2008, the accumulated rainfall dropped to around 200 mm, which is almost 50 % below the 2000–2010 total average of 368 mm, implying meteorological drought. During the hydrological years of 2006/2007 and 2008/2009, rainfall is generally below the 368 mm average. Semel deviates from the other values and has a lower precipitation than the other districts.

Vegetation conditions throughout the Duhok Governorate show considerable spatio-temporal variation for the period 2000–2010. Vegetation productivity was, on the whole, below normal in the northern and southern portions of the governorate in 2003 and 2008, respectively, while the years 2001 and 2010 show above normal vegetation productivity. Since the focus of this article is drought, these positive anomalies will not be further investigated. Figure 5 shows that EVI anomalies are moderately negative for the larger part of the governorate in 2003 and 2008, with many areas showing strongly negative anomalies. In 2003, Zakho and Amedi in the northeast were affected by negative anomalies in vegetation condition, while in 2008, the negative anomalies occurred mainly in the Semel, Duhok and Zakho Districts in the western part of the Duhok Governorate. MODIS quality assurance data show that in April 2003, there were 3,847 snow pixels in the study area, which is about 3,000 more than for the same date in 2006 (reference year). In 2008, there were no snow pixels for this date.

A quantitative interpretation of the drought year 2008 show that 66.2 % of the area had negative or strongly negative vegetation anomalies. Strongly negative anomalies were experienced by 18.5 % of the Duhok Governorate, while only 6.2 % had positive anomalies. 27.6 % of the area experienced near-normal vegetation conditions.

4.2 Socioeconomic aspects

In 2008, almost all surveyed villages were located in areas with below normal vegetation conditions. Figure 6 shows the location of the villages superimposed on the DEM. The

village colors are anomaly magnitudes and are consistent with the legend used to depict drought magnitudes in Fig. 5. All but four villages occur in areas with negative vegetation anomalies. Three of the villages are located in areas with strong negative anomalies and were located at both lower and higher elevations. The villages with no anomalies were all located at higher elevations (>1,000 m).

There are moderate levels of association between below normal vegetation amounts and number of households in a village reporting drought, cultivating land, and those with incomes originating from agriculture, respectively. The correlation analysis presented in Table 3 shows a moderate but highly significant relation between reported and measured drought ($\rho = -0.39$, $p = 0.005$), showing that villages with a stronger negative EVI anomaly had more households reporting drought as a problem. However, the relationship between the number of households reporting drought and households cultivating their land was slightly stronger ($\rho = 0.42$, $p = 0.003$). This means that villages with more agricultural activity are more susceptible to drought. The strongest relationship, however, was found between agricultural activity and agricultural income ($\rho = 0.57$, $p = 1.4e-05$). A weak positive relationship of low significance was found between irrigated land and vegetation anomaly ($\rho = 0.21$, $p = 0.12$).

Nine villages were chosen for a more detailed assessment of the drought's effect on the population, including a total of 92 household interviews (Fig. 6). The most affected and moderately affected villages (those falling into the median category, groups A and B) show negative EVI anomalies of between 1.7 and 2 standard deviations in 2008, but show only small negative anomalies in 2007 and 2009 (Figs. 7, 8). The precipitation data from TRMM, however, show a decrease in precipitation during the period 2007–2009, for all nine villages (Figs. 7, 8, 9). Villages C1–3 show little or no negative anomalies in 2008, but instead show a stronger negative EVI anomalies in 2003 (1.4–2 standard deviations below normal; Fig. 9).

Drought as a problem was frequently reported in villages A1, A2 and B3, where nearly 50 % of all households had experienced drought or lack of water (Table 4). But in A3, considered one of the three worst affected villages, only 11 % of the interviewed households reported drought. In the least affected villages, no households reported drought as a problem. Instead, households in C3 (100 %) and C2 (18 %) reported frost and cold weather as a problem.

Agricultural activity is above 50 % in all villages except B1 (4 %) and C1 (33 %), but only B2 and C3 has a high agricultural income level, where more than 70 % of the households rely on agriculture as their only income (Table 4). In the most affected villages (A1–3), dependence on agricultural income ranges from 0 to 33 %. Irrigation is larger than 50 % of the land in six of the villages, A2, A3, B1, B2, C2 and C3. In the worst affected village, A1, only 26 % of the land is irrigated, the rest relying on rainfall.

A visual interpretation of the agricultural land cover within the 2 km village buffer shows that A1 is surrounded by cereal fields of various sizes. The village is located less than 10 km from the Tigris River, which has long been a source of irrigation water (FAO Aquastat 2009). The buffer zone for B1 (located near the larger city of Zakho) is bisected by a river valley that provides water for some larger cereal fields and some smaller vegetable fields near the river. Much of the area is unused land with grass vegetation.

A3 and B3, located close to each other, show very small-scale agriculture with cereal cultivation, vegetables and orchards. The villages are located close to an urban center and the Greater Zab River.

The agricultural land cover around A2, B2, C1, C2 and C3, located in mountainous areas, consist mainly of orchards (but also some vegetable plantations) that are spread out
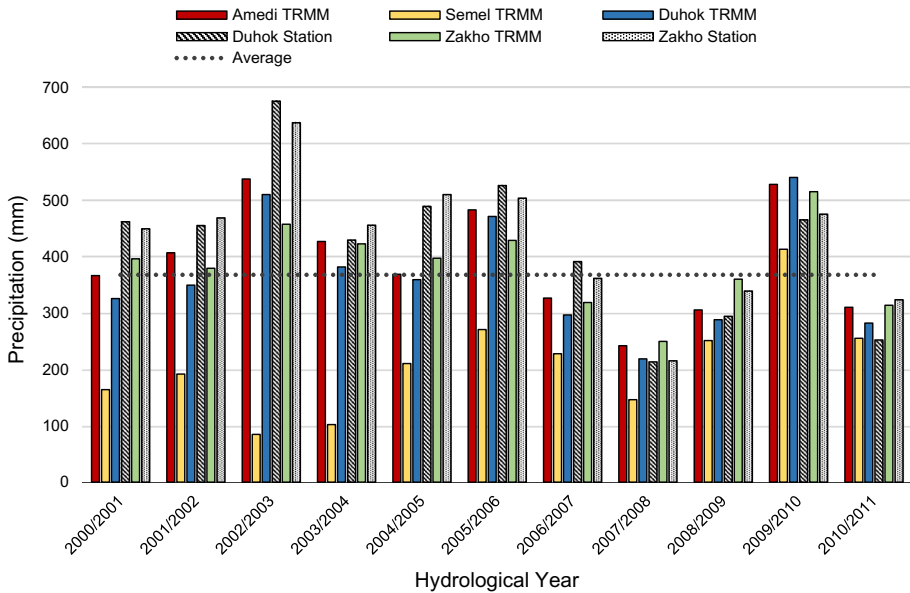
Fig. 4 Time series of precipitation during the rainy season (November–March) for hydrological years 2000/2001–2010/2011 and the average value based on station data and TRMM

in the valleys. Some of the orchards are terraced and the surrounding vegetation is sparse, with some shrubs or grasslands.

The average reported out-migration from the villages since 2006 amounted to 23 households in total from all nine villages. The villages most affected by the drought had a total of five reported out-migration events, while C2 alone, one of the least affected villages, had an average of nine reported out-migrations. C1, also one of the least affected villages, had an average of five reported out-migration events, making the least affected group accounting for more than 60 % of the out-migration.

5 Discussion

5.1 Meteorological and agricultural drought

The meteorological drought assessment shows that the Duhok Governorate was severely affected by a meteorological drought between the hydrological years 2006/2007 and 2008/2009. A drop of around 50 % in precipitation was consistently observed by satellite and ground-based measurements in the year 2008 (Fig. 5), similar to what Trigo et al. (2010) and Fadhil (2011) found. The precipitation data from Zakho and Duhok stations were visualized together with TRMM data to compensate for sparse data and to validate temporal variability with data of different sources. There are differences between TRMM and station data that can be explained by the larger extent of the TRMM data. It covers an area of approximately 30 by 30 km, which has a higher spatial variability than point measurements do. The Semel District had a much lower precipitation than the other
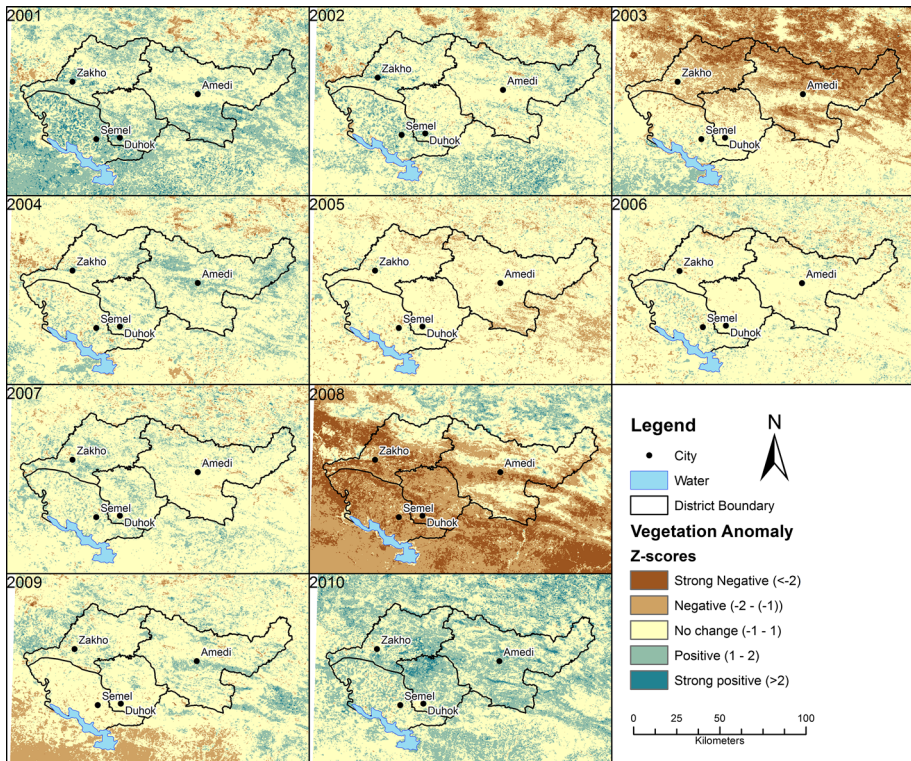
Fig. 5 Yearly spring time (March–June) vegetation anomalies (standardized EVI z scores) in the Duhok Governorate from 2001 to 2010. Note the negative anomalies in 2003 and 2008

districts, which can be explained by the fact that the Semel District is located south of the mountains, and is, therefore, in rain shadow.

Figure 5 shows that 2003 and 2008 had large areas with negative vegetation anomalies. In the hydrological year of 2002/2003, there was a large increase in precipitation (Fig. 4), but the EVI for 2003 showed a large negative anomaly, especially in the mountains of Amedi and Zakho (Fig. 6). The hypothesis that could explain the strong negative anomaly is an abnormally late snow melt leading to prolonged snow cover in the mountains, affecting the summed EVI of the vegetation period. Indeed, the abnormally high precipitation (in higher altitude areas snowfall) of up to 300 mm above average observed during this year (Fig. 4) supports this hypothesis, as do the quality assurance data from MODIS that reveal large snow covered areas in 2003. Furthermore, Zaitchik et al. (2007) maintain that an extensive snowpack from heavy winter snowfall in 2003 persisted through April in the higher elevations of Turkey and Iran.

The latest meteorological drought in the Duhok Governorate lasted for three consecutive hydrological years, (2006/2007–2008/2009), but the EVI anomalies (representing agricultural drought) only crop up in 2008. This confirms the results presented by Trigo et al. (2010), which state that the hydrological year 2007/2008 was the most acute drought year. The 2007 and 2009 EVI anomalies show very little, if any, indication of drought compared with 2008. It seems that the precipitation during the corresponding hydrological
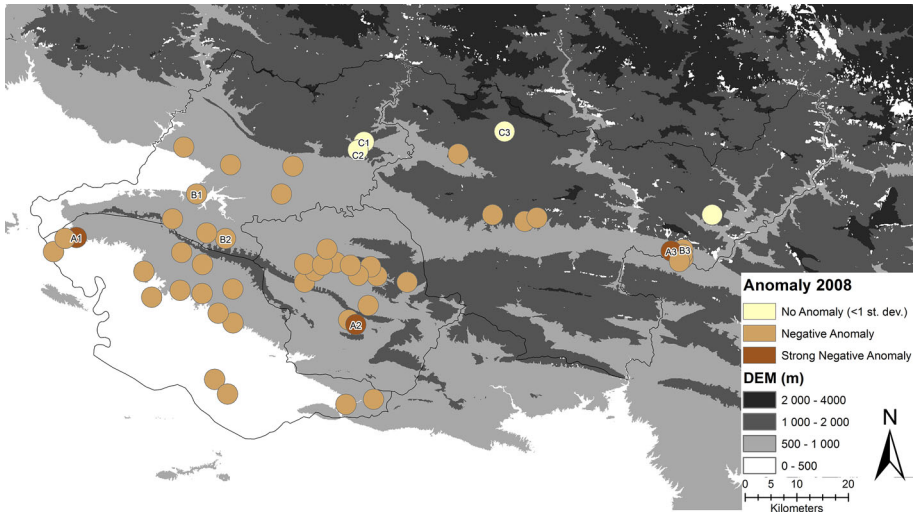
Fig. 6 Village buffer zones and their anomalies during the vegetation season 2008 on a Digital Elevation Model (ASTER GDEM is a product of METI and NASA). The nine villages are labeled with their aliases A1–3, B1–3 and C1–3

Table 3 Spearman ρ values showing the correlations between drought reported as a problem, EVI anomaly 2008, irrigation and agricultural activity in the 50 villages

	Reported drought	Anomaly 2008	Irrigation	Agricultural activity	Agricultural income
Reported drought	1				
Anomaly 2008	−0.39**	1			
Irrigation	−0.10	0.21	1		
Agricultural activity	0.42**	−0.05	0.26*	1	
Agricultural income	0.17	−0.08	0.20	0.57**	1

** Significant at the 0.01 level, * significant at the 0.1 level

years was not low enough to have a comparable effect on the vegetation, compared with 2007/2008. Additionally, irrigation might have played a role, reducing the impact of the drought in 2007 and 2009, while ground and surface water might have been insufficient in 2008 due to lack of precipitation. In order to shed light on these mechanisms, more information on hydrological conditions is necessary. Precipitation during 2009/2010 was just above average, but the EVI anomalies show positive anomalies across the whole area for 2010, indicating a rapid improvement in vegetation conditions after an increase in precipitation.

As much as 66.2 % of the Duhok Governorate had negative anomalies, and 18.5 % units witnessed a strong negative vegetation anomaly. Worst affected were low lying areas in Semel, Duhok and Zakho Districts, but also Amedi showed negative vegetation anomalies.
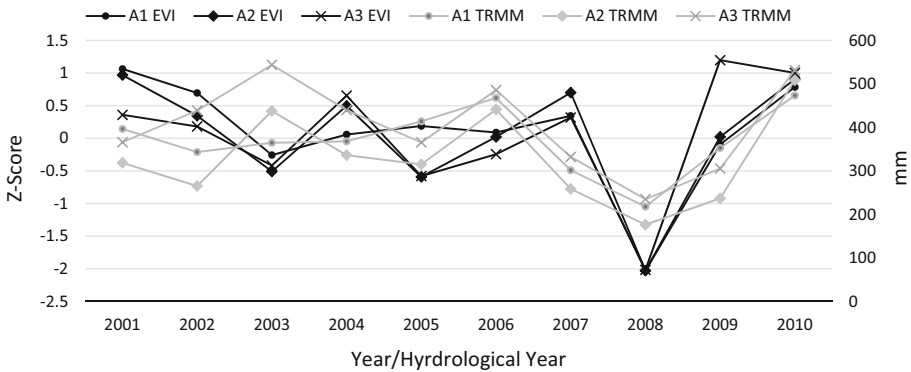
Fig. 7 Time series of EVI vegetation anomalies during the growing season averaged over the 2 km buffer zones and TRMM precipitation for the hydrological years in the three worst affected villages, A1–3, 2001–2010
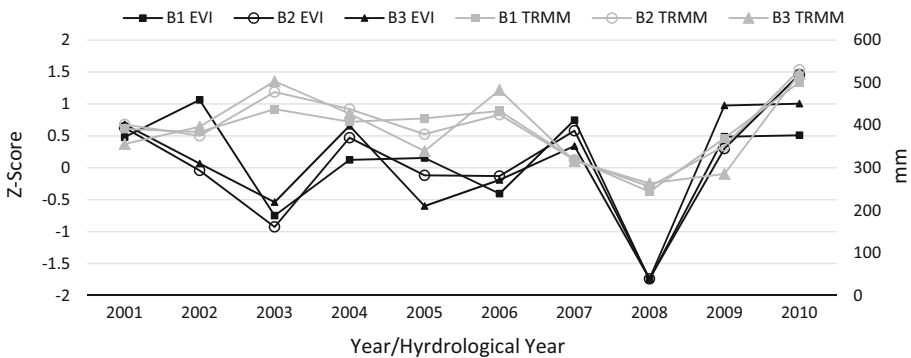

Fig. 8 Time series of EVI vegetation anomalies during the growing season averaged over the 2 km buffer zones and TRMM precipitation for the hydrological years in the three median affected villages, B1–3, 2001–2010

5.2 Socioeconomic aspects

The province-level biophysical assessment showed that a large part of the Duhok Governorate was exposed to negative vegetation anomalies in 2008, and the village level assessment showed that many of the sample villages were located in drought affected areas. Many of the villages that were exposed to drought also had frequently reported drought as a problem, but the reporting of drought was also highly related to the agricultural activity of the village.

All but four of the villages experienced negative anomalies of >1 standard deviations below normal in 2008. Furthermore, C3 was the only village with a z score slightly above zero, which means that 49 of 50 villages in a random sample had negative vegetation anomalies in 2008, representing 98 % of the sample.

The Spearman correlation analysis showed that perception of drought is to some extent negatively related to the strength of the anomaly (negative anomalies give a higher reporting of drought; $\rho = -0.39$, Table 3), but more strongly related to the agricultural
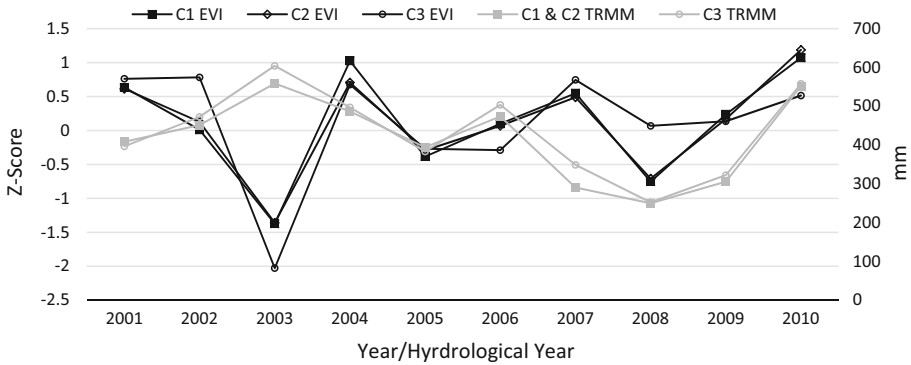
Fig. 9 Time series of EVI vegetation anomalies during the growing season averaged over the 2 km buffer zones and TRMM precipitation for the hydrological years in the three least affected villages, C1–3, 2001–2010 (the precipitation measures for C1 and C2 were the same, so they were combined into one chart element)

activity of the people ($\rho = 0.42$). This implies that the drought was mainly felt by people relying on water for agriculture. The correlation analysis did show a weak positive relationship between measured vegetation anomalies and irrigation ($\rho = 0.21$), indicating that the anomalies had been smaller in areas with more irrigation, but the significance of relationship was low. This implies that the irrigation did generally not help buffer the impact of the drought, as far as vegetation conditions are concerned. The relationship between agricultural activity and agricultural income ($\rho = 0.57$) was not surprising, since agricultural activity is required to have agricultural incomes. There was no significant relationship between reported drought and irrigation ($\rho = -0.1$) meaning that irrigation have not decreased the perceived vulnerability to drought in the 50 villages. People who irrigate their lands might still view drought as a problem, since it requires more water and energy resources, even though it does not mean crop failure.

Of the nine villages that were chosen for further discussion, six (A and B villages) had large negative EVI anomalies in 2008, while the C villages (least affected) had much smaller anomalies. Villages in group C had larger negative anomalies in 2003 (Fig. 9), a year with above average precipitation, which showed negative anomalies mainly in the mountains in the northeast. The explanation is that snowmelt in the mountains occurred later than usual, thereby affecting vegetation growth for the rest of the growing season, as discussed above. This is further corroborated by reported problems with frost and low temperatures in the affected villages (C2 and C3).

Vegetation conditions are interesting from a socioeconomic perspective if people in the affected areas rely on this type of natural resource for social or economic purposes. Agricultural activity was present in all nine villages, and seven of the villages had an agricultural activity in >50 % of the surveyed households. However, C3 and B2 were the only villages where many households (>70 %) relied only on agriculture for their income, while the worst affected villages had a low reliance on agriculture (<33 %). Diversification of income sources (common in the Duhok Governorate) leads to decreased drought vulnerability. Irrigation is another factor that decreases the reliance on rainfall and should, therefore, decrease the vulnerability to drought. The worst affected village, A1, did have a smaller amount of land irrigated than other villages, and the correlation analysis did show a

Table 4 Survey responses summarized for the villages

Village	Reported drought (%)	Reported frost (%)	Agricultural activity (%)	Agricultural income (%)	Irrigation (%)	Migration since 2006 (hh's)
A1	50	0	92	33	26	2
A2	47	0	47	11	77	3
A3	11	11	44	0	59	0
B1	4	4	4	0	100	1
B2	43	0	100	71	59	3
B3	50	0	100	0	27	0
C1	0	0	67	0	1	5
C2	0	18	82	18	78	9
C3	0	100	100	100	88	0

Reported drought and frost represent the proportion of people reporting it as an environmental problem. Agricultural activity shows the proportion of households in the village that cultivate land, while agricultural income represents the proportion of people who actually reported their own agriculture as a source of income. Irrigation represents the proportion of the interviewed households' land that is irrigated. Reported migration since 2006 represents an average of the number of households reported to have left the village

weak positive correlation between EVI anomaly and irrigation, but not significant enough to generalize a relationship.

Drought was reported as a problem in all villages that were severely affected by the drought, as shown by EVI data, compared with the least affected villages, where it was not reported as a problem. This implies that vegetation data are consistent with the interview data, and household surveys can indeed give an idea of whether a village was affected by the drought or not. Drought affected agriculture in the Duhok Governorate, but a low economic reliance on agriculture, due to decades of insecurity, mitigated the socioeconomic impact. The visual interpretation of land cover shows that agriculture is small scale and consists mainly of orchards in the mountains and cereal production in low-elevation villages, such as A1 and B1. These results contradict a publication by UNDP (2010), which reported widespread socioeconomic impacts in the Kurdistan Region. The UNDP (2010) report did not, however, state what kind of data these conclusions were based on, or in what particular regions people were most affected. A possibility might be that the Duhok Governorate was less affected than the Erbil and Sulaymaniyah governorates.

Reported migration from the villages since 2006 could not be associated with the biophysical drought severity of the village, as a large part of the migration was reported from the least affected villages (Table 4). This, further, challenges the UNDP (2010) report that states that drought led to an increase in rural to urban migration. In general, reported migration from villages was low and in many cases non-existent. A problem is that the validity of this type of secondary data is dependent on a number of factors, for example village size. In smaller villages, it is easier for the residents to know and remember who moves in or out, but in larger villages, this might not be the case. To assess the effects of drought on migration, better data are needed on both socioeconomic factors and migration patterns. The relationship between migration and environment is complex, and so far, little agreement about the role of environmental change in migration processes can be found [see for example Findley (1994), Massey et al. (2010), Van der Geest (2011) and Gray (2009)].

5.3 Additional considerations

One of the main difficulties working in Iraq is the scarcity of data. Although precipitation data were available, they were only provided by two stations, without exact positioning details for either one. The landscape of the Duhok Governorate varies greatly in topography and the location and altitude of the measuring stations could have a big influence on the measurements. In this study, the lack of precipitation data was compensated by using coarse-resolution TRMM precipitation data, together with vegetation condition data. These data have their limitations. For example, TRMM is not precipitation measured at ground level, but rather an estimation of precipitation based on cloud properties. The TRMM dataset has not been validated for the study area, but TRMM and station data follow a similar temporal pattern with the advantage of TRMM showing spatial differences in precipitation between districts. In assessments focusing on precipitation anomalies, and not absolute values, the accuracy of measurements are of less importance. This confirms TRMM as a useful data source for meteorological drought detection in data-sparse areas (Thiemig et al. 2012; Naumann et al. 2012; Rhee et al. 2010; Zeng et al. 2012). Additionally, EVI is not a direct measure of drought or vegetation conditions, but rather shows the earth surface greenness, and is considered to be closely linked to water availability. However, EVI and NDVI can be affected by snow, floods, clouds, sensor errors and atmospheric disturbance. These effects were minimized by using multi-temporal EVI data summed over the growing period (cf. Hird and McDermid 2009).

The survey data used were not solely developed for a drought assessment, and, therefore, only a limited type of information could be extracted. A drought survey with semi-structured or even more qualitative questions could have provided a more in-depth socioeconomic assessment of the drought. Despite these limitations, however, the survey data add value to the drought assessment by showing that many people in the affected areas had some relation to agriculture and that many of them had reported drought as a problem, but also that few of the affected villages were relying on agriculture for income. The survey covered the period 2000–2010 to match the MODIS data, and the questions about drought were as open as possible, to avoid interview bias. A time lag of 2–4 years between the drought (2007–2009) and the survey (2011) can be considered normal (compare with Population and Ecology Research Laboratory (PERL) n.d.). If the survey participants were affected by drought, they are likely to remember it for at least a few years after the drought period.

The sample size of the survey data and its representability for the whole population in the Duhok governorate is important to consider. Included in the survey were 4.5 % of the villages in the Duhok governorate, which, considering the low data availability in this area, is an important contribution to the knowledge base. The villages in this survey are spatially distributed over the governorate (see Eklund and Pilesjö 2012) and include villages with varying proximity to cities and economic activity. Even though it might not describe the whole population, it provides information with a high spatial resolution that is impossible to extract from secondary data sources such as censuses or other national surveys.

The approach of focusing on two spatial levels (province and village) is useful for minimizing problems associated with scale. For example, the Modifiable Area Unit Problem refers to how the units used in spatial analyses can take many different shapes and sizes, which in turn affects the (statistical) outcomes of analyses (Dark and Bram 2007). Furthermore, ecological fallacy, i.e., making assumptions about individuals based on group-level data, is common when using coarse-resolution data. The size and shape of the village buffer zones, however, also constitutes an expression of the MAUP in that they are artificially constructed boundaries within which we assess vegetation conditions, but this approach provides a more

detailed assessment than just using districts, municipalities or other socially constructed units for analysis, where data are averaged inconsistently over larger areas.

6 Conclusions

This study shows that the Duhok Governorate was severely affected by the 2007–2009 drought, especially in the year 2008, when a majority of the villages included in the assessment were exposed to vegetation anomalies close to -2 standard deviations, and 66 % of the area had negative vegetation anomalies, which indicates that this drought had consequences for agriculture as well as natural vegetation. The drop of around 50 % in precipitation represented a meteorological drought, and the high number of households in affected villages reporting drought as a problem also suggested a socioeconomic drought. In Semel, Duhok and Zakho Districts, the negative vegetation anomalies were most severe, while in Amedi, the situation was slightly better.

Drought were mainly reported as a problem in villages exposed to drought that had many households involved in agriculture; however, reliance on agriculture was low in the three worst affected villages. The violent history of Iraq and the Oil-for-Food programme have impeded the agricultural development. The Kurdistan Region, therefore, imports large amounts of food staples from other countries, which has led to a generally low dependence on agricultural income and in turn to a lowered socioeconomic susceptibility to drought and other environmental problems affecting agriculture. With the KRG's plans for self-sustainability, it is, however, important for policy makers to know the spatial characteristics of exposure and susceptibility to drought and other natural hazards.

In order to assess the complexity of a drought, a triangulation of data and methods is far more useful than focusing only on a single aspect and spatial level, or using only one data source. The negative vegetation anomaly detected in 2003 could have been wrongly interpreted as a drought unless compared with rainfall data. Furthermore, the decrease in rainfall in Semel in 2002/2003 and 2003/2004 could indicate a drought, but the vegetation data showed no negative anomaly. Finally, if all data show drought conditions, such as in 2008, only socioeconomic data can show to what extent society was affected, and what made people vulnerable.

References

Adler RF, Huffman GJ, Bolvin DT, Curtis S, Nelkin EJ (2000) Tropical rainfall distributions determined using TRMM combined with other satellite and rain gauge information. J Appl Meteorol 39:2007–2023. doi:10.1175/1520-0450(2001)040<2007:TRDDUT>2.0.CO;2

Alcantara C, Kuemmerle T, Prishchepov AV, Radeloff VC (2012) Mapping abandoned agriculture with multi-temporal MODIS satellite data. Remote Sens Environ 124:334–347. doi:10.1016/j.rse.2012.05.019

Baban S (2012) Agriculture and the road map to self-sufficiency in Kurdistan. Paper presented at the World Kurdish Congress 2012, Erbil, Iraq

Baumann M, Ozdogan M, Kuemmerle T, Wendland KJ, Esipova E, Radeloff VC (2012) Using the landsat record to detect forest-cover changes during and after the collapse of the Soviet Union in the temperate zone of European Russia. Remote Sens Environ 124:174–184. doi:10.1016/j.rse.2012.05.001

Belal A-A, El-Ramady H, Mohamed E, Saleh A (2014) Drought risk assessment using remote sensing and GIS techniques. Arab J Geosci 7:35–53. doi:10.1007/s12517-012-0707-2

Bonaccorso B, Bordi I, Cancelliere A, Rossi G, Sutera A (2003) Spatial variability of drought: an analysis of the SPI in sicily. Water Resour Manage 17:273–296. doi:10.1023/a:1024716530289

Center for Research on the Epidemiology of Disasters (CRED) (2014) The International Disaster Database

Clark ML, Aide TM, Grau HR, Riner G (2010) A scalable approach to mapping annual land cover at 250 m using MODIS time series data: a case study in the Dry Chaco ecoregion of South America. Remote Sens Environ 114:2816–2832. doi:10.1016/j.rse.2010.07.001

Dai A (2011) Drought under global warming: a review. Wiley Interdiscip Rev Clim Change 2:45–65. doi:10.1002/wcc.81

Dark SJ, Bram D (2007) The modifiable areal unit problem (MAUP) in physical geography. Prog Phys Geogr 31:471–479. doi:10.1177/0309133307083294

Dow K (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. Geoforum 23:417–436. doi:10.1016/0016-7185(92)90052-6

Dracup JA, Lee KS, Paulson EG Jr (1980) On the definition of droughts. Water Resour Res 16:297–302. doi:10.1029/WR016i002p00297

Eklund L, Pilesjö P (2012) Migration patterns in Duhok Governorate, Iraq, 2000–2010. Open Geogr J 5:48–58

Fadhil AM (2011) Drought mapping using geoinformation technology for some sites in the Iraqi Kurdistan region. Int J Digit Earth 4:239–257. doi:10.1080/17538947.2010.489971

Findley SE (1994) Does drought increase migration? A study of migration from rural Mali during the 1983–1985. Drought Int Migr Rev 28:539–553. doi:10.2307/2546820

Fisher J, Witkowski E, Erasmus B, Van Aardt J, Asner G, Wessels K, Mathieu R (2012) Human-modified landscapes: patterns of fine-scale woody vegetation structure in communal savannah rangelands. Environ Conserv 39:72–82

Food and Agriculture Organization of the United Nations (FAO) (2004) Rural Household Survey in Iraq vol 2, Northern Iraq. Rome

FAO Aquastat (2009) Euphrates–Tigris river basin. http://www.fao.org/nr/water/aquastat/basins/euphrates-tigris/index.stm. Accessed 2014-01-28

Ghulam A, Qin Q, Teyip T, Li Z-L (2007) Modified perpendicular drought index (MPDI): a real-time drought monitoring method. ISPRS J Photogramm Remote Sens 62:150–164. doi:10.1016/j.isprsjprs.2007.03.002

Giannecchini M, Twine W, Vogel C (2007) Land-cover change and human–environment interactions in a rural cultural landscape in South Africa. Geogr J 173:26–42. doi:10.1111/j.1475-4959.2007.00227.x

Gouveia C, Trigo RM, DaCamara CC (2009) Drought and vegetation stress monitoring in Portugal using satellite data. Nat Hazards Earth Syst Sci 9:185–195. doi:10.5194/nhess-9-185-2009

Gray CL (2009) Environment, land, and rural out-migration in the southern Ecuadorian Andes. World Dev 37:457–468. doi:10.1016/j.worlddev.2008.05.004

Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Change 15:199–213. doi:10.1016/j.gloenvcha.2005.01.002

Hammond R, McCullagh P (1978) Quantitative techniques in geography: an introduction. Clarendon, Oxford

Hardi C (2011) Gendered experiences of genocide: Anfal survivors in Kurdistan-Iraq. Ashgate Publishing Company, Farnham

Hayes MJ, Svoboda MD, Wilhite DA, Vanyarkho OV (1999) Monitoring the 1996 drought using the standardized precipitation index. Bull Am Meteorol Soc 80:429–438. doi:10.1175/1520-0477(1999)080<0429:mtduts>2.0.co;2

Heim RR (2002) A review of twentieth-century drought indices used in the United States. Bull Am Meteorol Soc 83:1149–1165. doi:10.1175/1520-0477(2002)083<1149:arotdi>2.3.co;2

Hird JN, McDermid GJ (2009) Noise reduction of NDVI time series: an empirical comparison of selected techniques. Remote Sens Environ 113:248–258

Huffman GJ et al (2007) The TRMM multisatellite precipitation analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. J Hydrometeorol 8:38–55

Human Rights Watch (1993) Genocide in Iraq—the Anfal Campaign Against the Kurds. New York

Iglesias A, Cancelliere A, Gabiña D, López-Francos A, Moneo M, Rossi G (eds) (2007) Drought management guidelines. European Commission—EuropeAid Co-operation Office Euro-Mediterranean

Regional Programme for Local Water Management (MEDA Water) Mediterranean Drought Preparedness and Mitigation Planning (MEDROPLAN)

International Organization for Migration (IOM) (2011) GIS-database

Integrated Climate Data Center (n.d.) SPI—Standardized Precipitation Index. http://icdc.zmaw.de/spi.html?&L=1

Karnieli A et al (2010) Use of NDVI and land surface temperature for drought assessment: merits and limitations. J Clim 23:618–633. doi:10.1175/2009jcli2900.1

Kummerow C, Barnes W, Kozu T, Shiue J, Simpson J (1998) The tropical rainfall measuring mission (TRMM) sensor package. J Atmos Ocean Technol 15:809–817. doi:10.1175/1520-0426(1998)015<0809:ttrmmt>2.0.co;2

Kurdistan Region Statistics Office (KRSO) (2012) Agricultural Areas In The Governorates Of Kurdistan Region

Kurdistan Region Statistics Office (KRSO) (2013) Summer Planted Area Report in Kurdistan Region (2012–2013)

Kurdistan Region Statistics Office (KRSO) (2014) Population 1977–2013

Kurdistan Regional Government (KRG) (2010) About Kurdistan Region: Contemporary History

Leyk S, Maclaurin GJ, Hunter LM, Nawrotzki R, Twine W, Collinson M, Erasmus B (2012) Spatially and temporally varying associations between temporary outmigration and natural resource availability in resource-dependent rural communities in South Africa: a modeling framework. Appl Geogr 34:559–568. doi:10.1016/j.apgeog.2012.02.009

Lloyd-Hughes B, Saunders MA (2002) A drought climatology for Europe. Int J Climatol 22:1571–1592. doi:10.1002/joc.846

Massey D, Axinn W, Ghimire D (2010) Environmental change and out-migration: evidence from Nepal. Popul Environ 32:109–136. doi:10.1007/s11111-010-0119-8

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: Eight conference on applied climatology, Anaheim, California, 17–22 January 1993. American Meteorological Society

METI and NASA (2011) ASTER GDEM v2, distributed by: USGS Earth Explorer

Metz HC (1988) Iraq: A Country Study Kurds

Meyer JA, Califano MG (2006) Good intentions corrupted: the oil-for-food program and the threat to the U.N., 1st edn. PublicAffairs, New York

Mubareka S, Ehrlich D (2010) Identifying and modelling environmental indicators for assessing population vulnerability to conflict using ground and satellite data. Ecol Indic 10:493–503. doi:10.1016/j.ecolind.2009.09.002

NASA Earth Observatory (n.d.) NDVI as an indicator of drought. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_3.php

Naumann G, Barbosa P, Carrao H, Singleton A, Vogt J (2012) Monitoring drought conditions and their uncertainties in Africa using TRMM data. J Appl Meteorol Climatol 51:1867–1874. doi:10.1175/JAMC-D-12-0113.1

Nicholson SE et al (2003) Validation of TRMM and other rainfall estimates with a high-density gauge dataset for West Africa. Part II: validation of TRMM rainfall products. J Appl Meteorol 42:1355

Palmer WC (1965) Meteorological drought. Office of Climatology, U.S Weather Bureau, Washington DC

Panu US, Sharma TC (2002) Challenges in drought research: some perspectives and future directions. Hydrol Sci J 47:S19–S30. doi:10.1080/02626660209493019

Population and Ecology Research Laboratory (PERL) (n.d.) Data descriptions and instruments. Chitwan Valley Family Study

QGIS Development Team (2014) QGIS Geographic Information System

Rhee J, Im J, Carbone GJ (2010) Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. Remote Sens Environ 114:2875–2887. doi:10.1016/j.rse.2010.07.005

Robards M, Alessa L (2004) Timescapes of community resilience and vulnerability in the circumpolar north. Arctic 57:415–427

Smit B, Pilifosova O (2003) From adaptation to adaptive capacity and vulnerability reduction. In: Smith JB, Klein RJT, Huq S (eds) Climate change, adaptive capacity and development. Imperial College Press, London

Solano R, Didan K, Jacobsson A, Huete A (2010) MODIS vegetation index user's guide (MOD13 series). Vegetation Index and Phenology Lab, The University of Arizona. http://vip.arizona.edu/documents/MODIS/MODIS_VI_UsersGuide_01_2012.pdf

Sönmez FK, Kömüscü AÜ, Erkan A, Turgu E (2005) An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. Nat Hazards 35:243–264. doi:10.1007/s11069-004-5704-7

Sourcepole (2013) OpenLayers Plugin

Su F, Hong Y, Lettenmaier DP (2008) Evaluation of TRMM multisatellite precipitation analysis (TMPA) and its utility in hydrologic prediction in the La Plata basin. J Hydrometeorol 9:622–640

Thiemig V, Zambrano-Bigiarini M, De Roo A, Rojas R, Levizzani V (2012) Validation of satellite-based precipitation products over sparsely Gauged African River basins. J Hydrometeorol 13(6):1760–1783

Trigo RM, Gouveia CM, Barriopedro D (2010) The intense 2007–2009 drought in the Fertile Crescent: impacts and associated atmospheric circulation. Agric For Meteorol 150:1245–1257. doi:10.1016/j.agrformet.2010.05.006

Tsakiris G, Vangelis H (2004) Towards a drought watch system based on spatial SPI. Water Resour Manage 18:1–12. doi:10.1023/B:WARM.0000015410.47014.a4

UNDP (2010) Drought—Impact Assessment, Recovery and Mitigation Framework and Regional Project Design in Kurdistan Region (KR)

USGS: United States Geological Survey (2009) USGS LandDAAC MODIS, version 4 edn. International Research Institute for Climate and Society

Van der Geest K (2011) North–South migration in Ghana: what role for the environment? Int Migr 49:e69–e94. doi:10.1111/j.1468-2435.2010.00645.x

Vicente-Serrano S (2007) Evaluating the impact of drought using remote sensing in a mediterranean. Semi-arid Reg Nat Hazards 40:173–208. doi:10.1007/s11069-006-0009-7

WFP Iraq - North Coordination Office (2001) "Oil For Food"—Food Basket Adequacy Assessment Survey (draft)

Wilhelmi O, Wilhite D (2002) Assessing vulnerability to agricultural drought: a nebraska case study. Nat Hazards 25:37–58. doi:10.1023/a:1013388814894

Wilhite DA, Glantz MH (1985) Understanding the drought phenomenon: the role of definitions. Water Int 10:111–120. doi:10.1080/02508068508686328

Zaitchik BF, Evans JP, Geerken RA, Smith RB (2007) Climate and vegetation in the middle east: interannual variability and drought feedbacks. J Clim 20:3924–3941. doi:10.1175/jcli4223.1

Zeng H, Li L, Li J (2012) The evaluation of TRMM multisatellite precipitation analysis (TMPA) in drought monitoring in the Lancang River Basin. J Geogr Sci 22:273–282. doi:10.1007/s11442-012-0926-1