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Agricultural abandonment and re-cultivation during and after the Chechen Wars in the northern Caucasus

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ABSTRACT

Armed conflicts are globally widespread and can strongly influence societies and the environment. However, where and how armed conflicts affect agricultural land-use is not well-understood. The Caucasus is a multi-ethnic region that experienced several conflicts shortly after the collapse of the Soviet Union, most notably the two Chechen Wars, raising the question how agricultural lands were changed. Here, we investigated how the distance to conflicts and conflict intensity, measured as the number of conflicts and the number of casualties, affected agricultural land abandonment and subsequent re-cultivation, by combining social, environmental and economic variables with remotely-sensed maps of agricultural change. We applied logistic and panel regression analyses for both the First Chechen War (1994–1996) and the Second Chechen War (1999–2009) and interacted conflict distance with conflict intensity measures. We found that agricultural lands closer to conflicts were more likely to be abandoned and less likely to be re-cultivated, with stronger effects for the First Chechen War. Conflict intensity was positively correlated with agricultural land abandonment, but the effects differed based on distance to conflicts and the intensity measure. We found little re-cultivation after the wars, despite abundant subsidies, indicating the potentially long-lasting effects of armed conflicts on land-use. Overall, we found a clear relationship between the Chechen Wars and agricultural land abandonment and re-cultivation, illustrating the strong effects of armed conflicts on agriculture.

1. Introduction

Armed conflicts often have tragic humanitarian consequences (Gates et al., 2012; Li and Wen, 2005) and can have far-reaching and long-lasting environmental effects (Dupuy et al., 2017; Nita et al., 2018). Military operations often target the environment (Austin and Bruch, 2000), and entail adverse environmental outcomes such as defoliation, water contamination and air pollution. For instance, the Vietnam War had devastating environmental effects due to the US' defoliation campaign (Westing, 1976). Similarly, the Gulf War (1990–1991) led to the destruction of more than 700 Kuwaiti oil fields and refineries, creating major atmospheric, marine, and coastal contamination (Gerges, 1993; Price et al., 1994). Conversely, armed conflicts can also benefit the environment. Habitat can be protected when people avoid areas of violence, exemplified by flourishing wildlife in the Demilitarized Zone between North and South Korea (Gaynor et al., 2016; Kim, 1997; Martin and Szuter, 1999). Assessing the diverse environmental outcomes of armed conflicts is therefore important.

One open question is how armed conflicts affect land use, particularly agriculture in the form of agricultural land abandonment or shifts in agricultural production during and after the conflicts (Baumann and Kuemmerle, 2016; Urdal, 2005). Several causal mechanisms through which conflicts affect agricultural land-use decisions are plausible. Armed conflicts can affect agricultural land-use directly through the destruction of agricultural fields and environmental contamination. For example, deliberate cropland destructions to destabilize the opposing

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parties were part of conflicts such as in Ethiopia (Hendrie, 1994), Guatemala (Tomuschat et al., 1999), and Rwanda (Baechler, 1996) even though the Article 54 of the 1977 Protocol to the 1949 Geneva Conventions prohibits to "*attack, destroy, remove or render useless objects indispensable to the survival of the civilian population, such as foodstuffs, agricultural areas for the production of foodstuffs, crops, livestock, drinking water installations and supplies and irrigation works*". Furthermore, environmental contamination, such as soil and water pollution, can reduce land productivity and affect land-use directly (Formoli, 1995). Indeed, a substantial portion of the available agricultural land in many countries cannot be used as a result of conflicts (Biswas, 2001; Trevelyan et al., 2002).

In addition to the direct effects of armed conflicts on land use, they can also affect institutions, infrastructure, technology, the economy or the population, and those changes can be indirect causes of agricultural land-use change (Keen, 2000; Serneels and Verpoorten, 2015). Institutions' capacity to act is often limited during armed conflicts. Chaos and instability can damage the agricultural sector through a loss of market access and a shortage of agricultural inputs (e.g. seeds, fertilizer). As a result, farming can be less productive and more costly (ICRC, 2007). Alternatively, armed conflicts can stimulate agriculture when agricultural revenues fund war parties. For instance, the Islamic State in Syria and Iraq (ISIS) forced landowners to continue agricultural production because agriculture was an important source of income (Jaafar and Woertz, 2016). Military operations destroying transportation infrastructure can reduce access to markets, which disrupts agriculture (FAO, 2000; Unruh and Shalaby, 2012). Armed conflicts also limit the incentives in investments in technologies, making agricultural production primitive and costly (Brück, 2001). Demographic changes due to, for example, ethnic cleansing and soldier recruitment during the armed conflicts can create labor shortages that constrain agricultural activities (Suthakar and Bui, 2008). Internally displaced persons (IDPs), however, may increase agricultural activities at their destination locations while reducing them at their origins (Gbanie et al., 2018). For example, the 1994 genocide in Rwanda displaced three out of four farmers, and hence agricultural activity (FAO, 2000).

Despite many plausible mechanisms for how armed conflicts may lead to agricultural land-use change, empirical evidence for such links is not conclusive (Baumann and Kuemmerle, 2016). Agricultural land abandonment was prevalent in the conflict areas of Bosnia (Witmer, 2008), Colombia (Sánchez-Cuervo and Aide, 2013), Kosovo (Douarin et al., 2012), Lebanon (Darwish et al., 2009), Nicaragua (Stevens et al., 2011), and Sri Lanka (Suthakar and Bui, 2008), while both agriculture abandonment and expansion occurred in the Caucasus (Baumann et al., 2015), Iraq (Jaafar and Woertz, 2016), Syria (Eklund et al., 2017), Sierra Leone (Gbanie et al., 2018), and Sudan (Alix-Garcia et al., 2013). Similarly, post-conflict agricultural land-use change can be complex. For instance, agricultural land abandoned during a conflict may be re-cultivated after its end (Wilson and Wilson, 2013), but it may also be permanent if the armed conflict affected both land tenure and institutions and introduced new rules of land-use and management (United Nations, 2012).

Given equally plausible potential outcomes, predicting the effect of armed conflicts on agricultural land-use is difficult. One reason is that armed conflicts can have different effects on agricultural land-use depending on the intensity of the conflict (Biswas, 2001; Ordway, 2015), and the effect of armed conflicts on agriculture can depend on the distance to the conflicts. Areas closer to the conflict sites have typically higher land-use change rates, while regions afar are less affected (Baumann et al., 2015; Witmer, 2008). It is also crucial to control for potential other drivers such as environmental conditions as well as to account for possible unobserved factors (Butsic et al., 2015; Gorsevski et al., 2013; Sánchez-Cuervo and Aide, 2013). Statistical techniques to do so are increasingly available, such as propensity score matching (Alix-Garcia et al., 2012), structural equation models (Grinfelde and Mathijs, 2004), panel regressions (Allison, 2009) or Bayesian networks (Frayer et al., 2014), and can assist in establishing causality when combined with qualitative approaches.

The northern Caucasus is an ideal region to explore the land-use outcomes of armed conflicts. After the collapse of the Soviet Union in 1991, several armed conflicts took place in the region, among which the two Chechen Wars (First 1994–1996, Second 1999–2009) were some of the most violent confrontations in Europe since World War II, with 80,000–250,000 civilian casualties, and more than 800,000 internally displaced persons (IDP) (IDMC, 2018; Russell, 2005). Three years after Chechnya declared independence, Russia launched a 21-month campaign, the First Chechen War, which ended in 1996 when Russian forces withdrew and Chechnya gained *de facto* independence, albeit with rampant corruption, revolts, and crime (Zürcher, 2007). Furthermore, after Chechen rebels invaded Dagestan to establish a fundamentalist Islamic state, Russia responded with a new campaign in 1999, the Second Chechen War, which later transformed into a 'war on terror' against Islamic fundamentalist (Zabyelina, 2013). In 2009, the pro-Moscow Chechen government announced the end of the counter-terrorism operation, and while stability was largely reinstalled, clashes with militants and insurgencies remained common throughout the northern Caucasus (Holland et al., 2018; O'Loughlin et al., 2011; O'Loughlin and Witmer, 2012). Though the social, political and economic consequences of the Chechen Wars have been evaluated, how agricultural land-use were altered during and after the conflicts remained unknown (Vendina et al., 2007; Williams, 2001; Witmer and O'Loughlin, 2011).

Advances in land-use mapping and armed conflict data now provide an opportunity to investigate the complex interactions between agriculture and armed conflicts in this region. Spatially explicit information on the timing of agricultural land-use change, for instance, is necessary to quantitatively assess the consequences of the armed conflicts on agriculture land-use. Recently, dense time series of satellite images allow us to analyze land-use change at high temporal and spatial resolution, e.g., with 30-m Landsat imagery in the northern Caucasus (Yin et al., 2018). Using this dataset, along with the database on conflicts and unrests developed by Uppsala Conflict Data Program (UCDP, Sundberg and Melander, 2013), our goal was to assess the relationships of armed conflicts during and after the Chechen wars with agricultural land abandonment and re-cultivation. Specifically, we ask the following questions:

1) How much agricultural land was abandoned and re-cultivated in the conflict area?
2) Was agricultural land abandonment more likely in areas closer to conflicts?
3) Was agricultural land abandonment more likely in areas with higher conflict intensity?

2. Study area and methods

2.1. Northern Caucasus

Our study area covered the North Caucasian Federal District of Russia, including parts of the Chechen Republic, the Republic of Ingushetia, the Republic of North Ossetia-Alania, the Republic of Kabardino-Balkaria and Stavropolskij Kraj (Stavropol). The study area is divided into the southern highland and the northern lowland. The southern highland contains the foothills of the Greater Caucasus Mountains, and the northern lowland consists of the Terek River basin (Fig. 1). The climate is continental with average temperature changing from −4 °C in January to 24 °C in July, and the annual precipitation ranges from 500 mm on plains to 1000 mm in the foothills. The common soils in the study region are very fertile chernozem and the less common chestnut soils (Afonin et al., 2008).

Environmental conditions make the northern Caucasus well-suited for crop production and resulted in the highest grain yield of Russia in

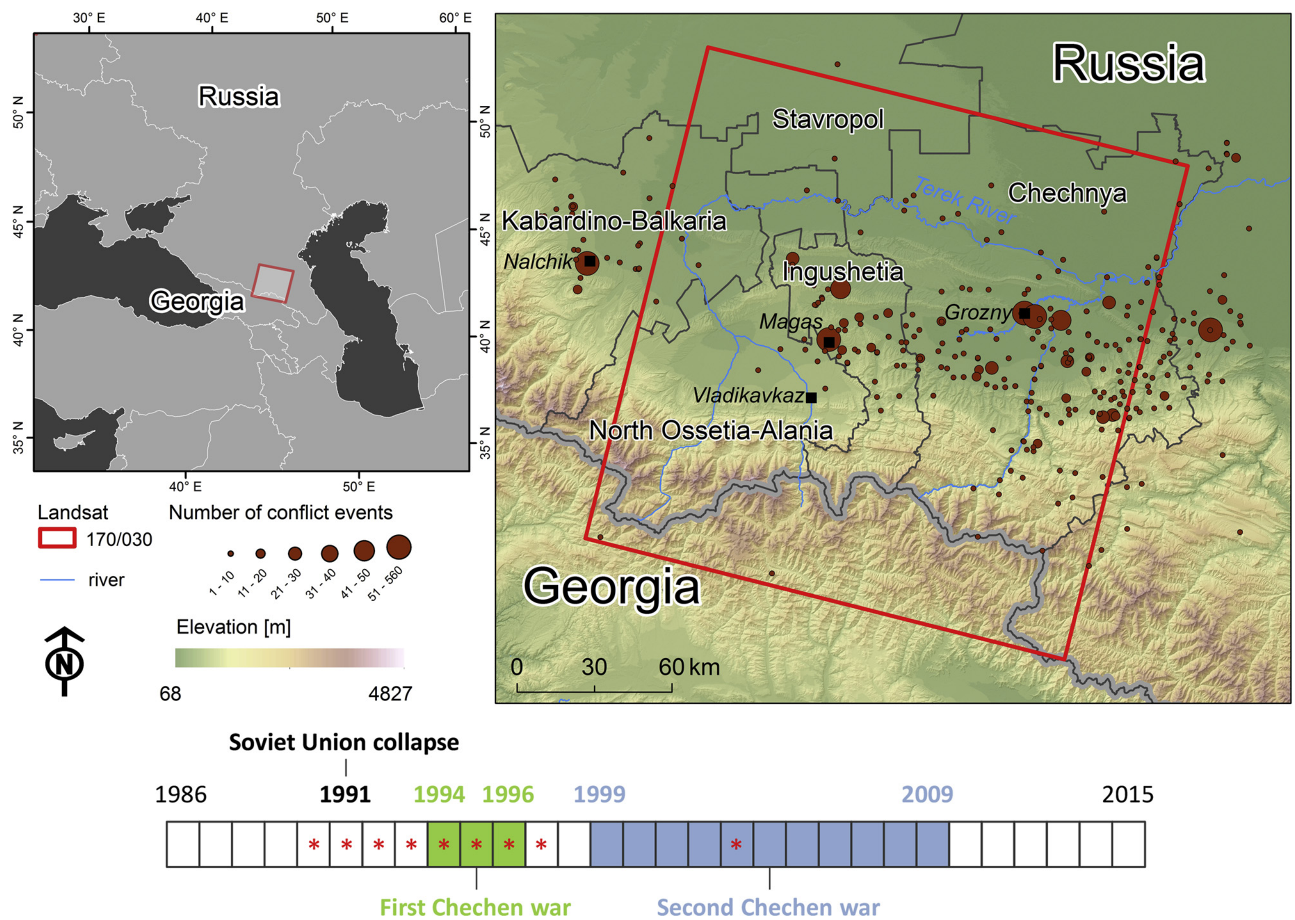

Fig. 1. Conflict events in the northern Caucasus from 1989 to 2011 according to the Uppsala Conflict Data Program (Sundberg and Melander, 2013). A conflict event is defined as "an incident where armed force was used by an organized actor against another organized actor, or against civilians, resulting in at least one direct death at a specific location and a specific date" (Sundberg and Melander, 2013). The figure in the bottom shows the timeline of the collapse of the Soviet Union, and the Chechen Wars. The red asterisk indicates a lack of Landsat observations in the dataset of Yin et al. (2018) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

the Soviet times (FAO, 2009; Ioffe et al., 2004). However, since the 1990s, the agricultural sector in the northern Caucasus went through a drastic transition as Russia transformed its economy from central-command to market-oriented. After the collapse of the Soviet Union, the large-scale state (*sovkhoz*) and collective (*kolkhoz*) farms were gradually privatized in Russia (Uzun et al., 2014). The Land Code of the Russian Federation gives regions the right to decide the date and type of land reform. The Stavropol region underwent privatization, but a full-fledged land market and complete private land ownership was not established (Kolosov et al., 2017). Especially the adjustment of property and field boundaries was both technically challenging and resisted by ethnic, administrative, and business elites. As a result, the field boundaries of former collective farms were kept, and relatively few modern agro-complexes specialized in grain and flour production emerged. In contrast, Chechnya, Dagestan, Ingushetia, Kabardino-Balkaria and North Ossetia did not legislate any formal land privatization, though in practice lands often belong to elites (Caucasian Knot, 2013), and *de facto* privatization by farmers occurred in some places (Gunya, 2017). In Chechnya, for example, the state regulates access to land while district municipalities regulate land in other republics. As a result, legislative contradictions concerning the status and use of agricultural lands are prevalent in the northern Caucasus (Koehler et al., 2017). In terms of agricultural land use, abandonment has been widespread throughout Russia since the early 1990s due to the termination of large subsidies to agriculture (Ioffe and Nefedova, 2000). Armed conflicts may have exacerbated this decline in agriculture in the northern Caucasus. For example, a household survey conducted in Chechnya and Ingushetia before and after the conflicts found a major decline in agricultural output and productivity (OCHA, 2005).

2.2. Remotely sensed land-use change

To understand the relationships between the Chechen Wars and agricultural land-use change, we analyzed spatial and temporal variations in agricultural land abandonment and re-cultivation relative to the locations of armed conflicts, and to spatial variation in key biophysical and accessibility factors.

To estimate agricultural land-use change between 1986 and 2011, we analyzed a map of stable (active) agriculture, agricultural abandonment, re-cultivation of abandoned lands, and fallow land from Landsat imagery for one Landsat footprint path 170 and row 030 that we classified previously (Yin et al., 2018). We selected this Landsat footprint because it covers most of Chechnya and Ingushetia and it included the vast majority (83%) of conflict events in the northern Caucasus according to the Uppsala Conflict Data Program Georeferenced Event Dataset (Section 2.3).

In that map, agricultural land abandonment was defined as agricultural land that had not been used for at least five years (FAO, 2016) and re-cultivation as abandoned agricultural land that was re-used for more than four years. These maps were generated based on a total of 301 Landsat images obtained from the United States Geological Survey (USGS, 236 images) and the European Space Agency (ESA, 65 images). We estimated annual active agricultural land probability using a machine learning approach and recorded the timing of agricultural land abandonment and re-cultivation based on temporal segmentation. Because of an eight-year data Landsat gap from 1990 to 1997, we aggregated agricultural land abandonment between 1989 and 1998 into one class (Fig. 1). Agricultural land abandonment classes had producer's and user's accuracies of 69% and 66%, while re-cultivation had producer's and user's accuracies of 71% and 57%, respectively (Yin et al., 2018).

We calculated agricultural land abandonment and re-cultivation rates at certain distances to the nearest conflict event (Section 2.3). Abandonment rates were calculated as the proportion of abandoned pixels relative to all agricultural land at each distance interval (i.e., < 1 km, 1–3 km, 3–6 km, 6–9 km and > 9 km). Re-cultivation rates were calculated as the percentages of abandoned lands that were re-cultivated.

2.3. Conflict events and other variables

We selected the Uppsala Conflict Data Program (UCDP) Georeferenced Event Dataset (GED) to model the influence of the conflicts on agricultural land-use (Sundberg and Melander, 2013). While there are other conflict datasets (e.g. Holland et al., 2018), we selected the GED because of its longer time coverage (starting in 1989). The UCDP defines a conflict event as “an incident where armed force was used by an organized actor against another organized actor, or against civilians, resulting in at least one direct death at a specific location and a specific date” (Sundberg and Melander, 2013). The GED provides detailed spatial and temporal information of individual conflict events across the globe. Different aspects of a conflict event include the best estimate of the number of dead civilians (civilian casualties) and total casualties. We extracted all events in our study area and the surrounding regions from 1989 to 2011 (Fig. 1). We used only records with high-confidence geolocation precision, which was the case for 83% of them. For sites that experienced multiple conflict events within one year, we summed the number of conflict events and the number of casualties, including civilian casualties and total casualties. In total there were 2329 recorded conflict events in our study area and study period.

Agricultural land-use change can be caused by many factors other than conflicts (Geist and Lambin, 2002; Meyfroidt et al., 2016; Osawa et al., 2016) that need to be accounted for when estimating the effects of armed conflicts. We included three groups of control co-variables in our models: institutional and economic factors, environmental factors, and accessibility factors (Table 1). For institutional and economic factors, we added a dummy variable “region” in the model to control for the potential influence of regional governmental management and policies across five republics/Kraj in the northern Caucasus. Environmental variables, such as elevation, topographic slope, and soil organic matter, determine yields and are closely linked to agricultural land abandonment in European Russia (Prishchepov et al., 2013). The soil organic matter was compiled from the European Soil Database (Panagos et al., 2012), which divided our study area into 17 zones. Regarding accessibility, we calculated the distance of pixels to agricultural land, to the nearest settlement, road, and river. Settlements were identified manually based on Yin et al. (2018) with the aid of the OpenStreetMap (www.openstreetmap.org). We also added longitude and latitude to each sample in the models to account for spatial autocorrelation. We did not include demographic data in our models because the population data in the northern Caucasus was unfortunately incomplete and unreliable.

2.4. Model design

We used a series of statistical techniques to quantify the effects of the Chechen Wars on agricultural land change including logistic, fixed-effects, and random-effects regression models (Table 2). We modeled land-use change for the First and the Second Chechen War separately,

Table 1
List of variables used for quantifying the influence of the Chechen Wars on agricultural land-use change.

	Category	Variable description	Period	Unit	Source
Response variables	Agricultural land-use change	Agricultural land abandonment	1986-1989, 1998-2011	1: abandonment, 0: no abandonment	Yin et al. (2018)
		Abandoned agricultural re-cultivation	1999-2011	1: re-cultivation, 0: no re-cultivation	Yin et al. (2018)
Conflict co-variables	Conflict distance	The distance to the nearest conflict event	1989-2011	km	Sundberg and Melander (2013)
	Conflict intensity	Number of conflict events	1989-2011	number	Sundberg and Melander (2013)
		The best estimate of dead civilians in an event	1989-2011	number	Sundberg and Melander (2013)
		The most likely estimate of total casualties resulting from an event	1989-2011	number	Sundberg and Melander (2013)
Control co-variables	Institution/ economics	Region delineation	Static	dummy	OpenStreetMap contributors (2017)
	Biophysical environment	Elevation	Static	m	Farr et al. (2007)
		Slope (topography)	Static	degree	Farr et al. (2007)
		Top soil organic matter content	Static	%	Panagos et al (2012)
	Accessibility	Euclidean distance to the nearest settlement	Static	km	Calculated based on Yin et al. (2018)
		Euclidean distance to the nearest road	Static	km	Calculated based on OpenStreetMap contributors (2017)
		Euclidean distance to the nearest main river	Static	km	Calculated based on OpenStreetMap contributors (2017)
	Geo-location	Longitude and latitude	Static	m (UTM zone 38 N)	Yin et al. (2018)

Table 2
List of models used in this study. Response variables (i.e., agricultural abandonment, re-cultivation) are highlighted in green color while selected control co-variables and independent variables are highlighted in grey color for each model.

Model No.	Model type	Abandonment	Re-cultivation	Elevation	Slope	Soil organic matter	Distance to settlement	Distance to river	Distance to road	Region	Longitude	Latitude	Distance to conflict event	Conflict event Number	Civilian casualties	Total casualties	Period
I-1	logit	■		■	■	■	■	■	■	■	■	■	■	■			1989-1998
I-2	logit	■		■	■	■	■	■	■	■	■	■	■		■		1989-1998
I-3	logit	■		■	■	■	■	■	■	■	■	■	■			■	1989-1998
II-1	fixed-effects	■											■	■			1999-2011
II-2	fixed-effects	■											■		■		1999-2011
II-3	fixed-effects	■											■			■	1999-2011
III-1	random-effects	■		■	■	■	■	■	■	■	■	■	■	■			1999-2011
III-2	random-effects	■		■	■	■	■	■	■	■	■	■	■		■		1999-2011
III-3	random-effects	■		■	■	■	■	■	■	■	■	■	■			■	1999-2011
IV	random-effects		■	■	■	■	■	■	■	■	■	■	■				1999-2011

because of differences in data structure. For the First Chechen War, we only had one agricultural land abandonment class (land abandonment 1989–1998) due to a lack of Landsat data from 1990 to 1997 (Fig. 1), while for the Second Chechen War annual data on agricultural land abandonment and re-cultivation was available, making it well-suited for panel analysis.

Satellite image classifications contain millions of pixels and hence observations, but most of them are spatially autocorrelated. To increase computational speed and reduce spatial autocorrelation, we randomly sampled 5% of all pixels in the map and included coordinates of all the pixels in the models (Section 2.3). In all, 29,968 pixels of agricultural land abandonment and 294,037 pixels of non-abandoned agricultural land from 1989 to 1998 were selected for modeling. About 8.4% and 8.0% of the selected pixels showed agricultural land abandonment during the First and the Second Chechen War, respectively. About 15.8% of the selected abandonment pixels were re-cultivated later. To assess how distance to conflict affected the probability of agricultural land abandonment, we calculated the distance of each pixel to the closest conflict site. To understand the influence of conflict intensity, we analyzed the number of conflict events, civilian casualties, and total casualties (Strandow et al., 2014; Vité, 2009). We assigned the number of conflicts, civilian casualties, and total casualties from the closest conflict site to a given pixel, and calculated elevation, slope, and soil top organic matter for each pixel based on the 30-m SRTM DEM and 1-km European Soil Database. We also calculated the distances of each pixel to the nearest paved road and to the nearest river using the OpenStreetMap (www.openstreetmap.org) data. We performed log transformation on the control co-variables and conflict intensity measurements.

We fitted three logistic regression models to explain agricultural land abandonment between 1989 and 1998 (Eq. (1)). Each of the three models included one of the conflict intensity measurements, i.e., either the number of conflicts, the number of civilian casualties, or the number of total casualties, as an explanatory variable as well as additional control co-variables (Table 2). In each regression model, we interacted the conflict intensity variable with the distance to the conflicts. To better understand the local effect of the conflicts on land abandonment we plotted the marginal effects of conflict number, civilian casualties, and total casualties for multiple conflict distance levels. The marginal effects illustrate the changes in predicted probabilities of the dependent variable (outcome) when a specific covariate changes while all other co-variables are assumed to be held constant. To compare the marginal effects of the two Chechen Wars, we standardized the marginal effects of the Second Chechen War by integrating annual predicted probabilities over the whole observation period. Thus, the marginal effects of the First Chechen War represented the likelihood of agricultural land abandonment over the period 1989–1998 while the marginal effects of the Second Chechen War showed the likelihood of change during 1999-2011.

$$y_i = B_1 * C_i + B_2 * D_i + B_3 * C_i * D_i + B_{4-12} * E_i + \varepsilon_i \quad (1)$$

where y_i is agricultural land abandonment (1) or not (0) for pixel i during 1989–1998, C is the log of the conflict intensity measurement (i.e. conflict number, casualties) for pixel i during 1989–1998, D is the log of the distance to the nearest conflict event for pixel i during 1989–1998, E_i is a vector of covariates including the log of elevation, slope, soil organic matter, distances to the nearest settlement, river and road, the regional dummy variable, the longitude and latitude for pixel i, the B s are the coefficients to be estimated and ε represents an error term.

Second, we parameterized panel regression models (i.e., models based on datasets that have repeated observations), both fixed-effects and random-effects models, to investigate the effect of the Second Chechen War on agricultural land abandonment, a period for which we had annual data of agricultural land-use change. We used the definitions most common in econometrics, where fixed- and random-effects models are defined by their error structure. The fixed-effects regression model has advantages because it controls for all stable, unobservable variables, and it has been widely used in land use science and the social sciences (Allison, 2009; Arima et al., 2011; Seto and Kaufmann, 2003). The random-effects model, however, has the advantage of providing coefficients for time-invariant variables, which cannot be estimated in fixed-effects models. For the panel models, we labeled each pixel in each year as either abandoned or non-abandoned. For instance, if a pixel was abandoned in 2006, it was labeled as "abandonment" in 2006 and "non-abandoned" from 1999 to 2005. Therefore, our models can be interpreted as linear probability models, which have been effectively used for modeling land-use change elsewhere (Butsic et al., 2017). Again, we calculated the distance of each pixel to the nearest conflict event, and the number of conflict events, civilian casualties, and total casualties. We then ran three fixed-effects models interacting the distance to conflict event with one of the conflict intensity measures and calculated the marginal effects of each model (Eqs. (2) and (3)).

$$y_{it} = B_1 * C_{it} + B_2 * D_{it} + B_3 * C_{it} * D_{it} + \varepsilon_{it} \quad (2)$$

where y_{it} is agricultural land abandonment (1) or not (0) for pixel i at year t, C is the log of the conflict intensity measurement (i.e. conflict number, casualties) for pixel i at year t, D is the log of the distance to the nearest conflict for pixel i at year t, the B s are the coefficients to be estimated, and ε represents random variation.

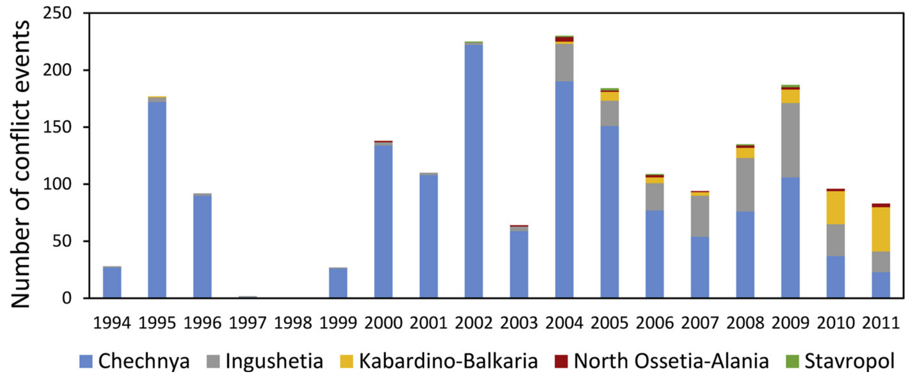

Fig. 2. The number of conflict events in the study area.

$$y_{it} = B_1 * C_{it} + B_2 * D_{it} + B_3 * C_{it} * D_{it} + B_{4-12} * E_i + \varepsilon_{it} \quad (3)$$

Third, we followed the same approach to investigate the effect of armed conflicts on re-cultivation (Eq. (4)). Because re-cultivation was much less common, we fitted models using only distance to conflicts as an independent variable to predict re-cultivation.

$$z_{it} = B_1 * D_{it} + B_{2-10} * E_i + \varepsilon_{it} \quad (4)$$

where z_{it} is agricultural re-cultivation (1) or not (0) for pixel *i* at year *t*.

3. Results

3.1. Spatio-temporal pattern of the armed conflicts

During the First Chechen War (1994–1996), most of the conflicts occurred in Chechnya, which accounted for 96% of the conflict events in our study area. The same holds true for the early stage of the Second Chechen War (1999–2003) when conflict events were also concentrated in Chechnya. However, in the later stage of the Second Chechen War (2004–2009), conflicts spread to the surrounding regions especially Ingushetia. In the post-Chechen War era the number of conflict events decreased but were more widely spread (Fig. 2).

3.2. Land abandonment and re-cultivation

We found more agricultural land abandonment in areas that were closer to armed conflicts (Fig. 3). About 44.9% of agricultural land within 1 km from conflicts was abandoned. Agricultural land abandonment rates gradually decreased with distance to conflicts. For example, > 9 km afar from a conflict, only 5.9% of agricultural land was abandoned. We found higher re-cultivation of abandoned agricultural land that was farther from conflicts. Nearly 27.9% of abandoned land was re-cultivated > 9 km afar from conflicts, compared to 5.9% within 1 km.

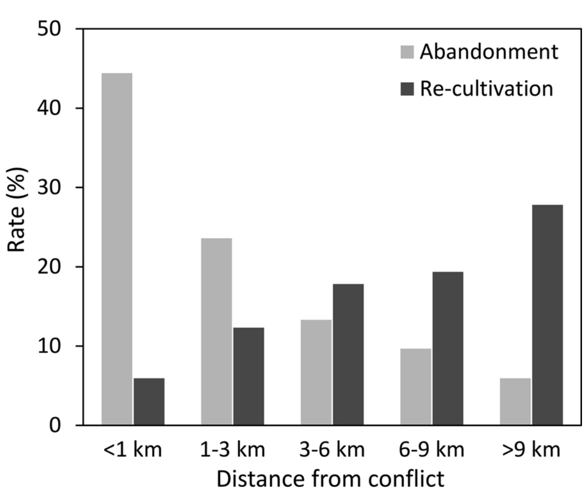

Fig. 3. Agricultural land abandonment and re-cultivation rates at different distances to conflicts. If the conflict events occurred within a settlement, the distance was calculated from the border of the settlement.

3.3. Local effects of the armed conflicts

Our models confirmed a strong correlation between the distance to armed conflicts and agriculture land abandonment. Both logit and panel regression models suggested that areas closer to armed conflicts had a higher probability of agricultural land abandonment (Fig. 4). During the First Chechen War, agricultural land < 1 km of a conflict had the highest land abandonment probability. For instance, the probability of agricultural land abandonment in relation to three conflict events was 43.7% if these events were located within 1 km, while the probabilities of abandonment were 27.5% and 5.7% for 1–2 km and > 8 km distance respectively (Fig. 4, model I-1). Similarly, during the Second Chechen War, the fixed-effects model showed that agricultural lands that < 1 km from a conflict had the highest abandonment probability (Fig. 4, model II). For instance, the abandonment probability of three conflict events decreased from < 1 km (31.7%) to > 8 km (8.2%) (Fig. 4, model II-1). Regardless of the conflict event number, the probability of agricultural land abandonment during the First Chechen War decreased from < 1 km (44.7%) to > 8 km (6.7%) (Fig. 4, model I-1). During the Second Chechen War the probability of abandonment decreased from < 1 km (32.5%) to > 8 km (8.3%) using fixed-effects model (Fig. 4, model II-1), and decreased from < 1 km (25.4%) to > 8 km (7.3%) using random-effects model (Fig. 4, model III-1). Unlike agricultural land abandonment, re-cultivation was more likely at longer distances from conflicts. For example, the probability of re-cultivation was five times higher when 16 km afar from conflicts than within 2 km (Fig. 5).

3.4. Effects of conflict intensity

The effects of conflict intensity on agriculture land abandonment varied among conflicts, location, intensity measurement, and models used. The results from the First Chechen War suggested a higher chance of abandonment in agricultural areas that experienced a higher number of conflicts (Fig. 4, model I-1). For instance, the probability of abandonment within 1 km of conflicts increased from 38.2% to 56.8% for one versus more than nine conflicts respectively. However, the number of conflicts only mattered within 6 km of conflicts. Similarly, the probability of abandonment increased with the increase of civilian casualties and total casualties, but the magnitude of their effects was lower than for the number of conflicts (Fig. 4, model I-2, I-3). Lastly, there were no significant differences in the abandonment probability when there were more than ten casualties (Fig. 4, model I-2, I-3).

During the Second Chechen War, our fixed effect models showed

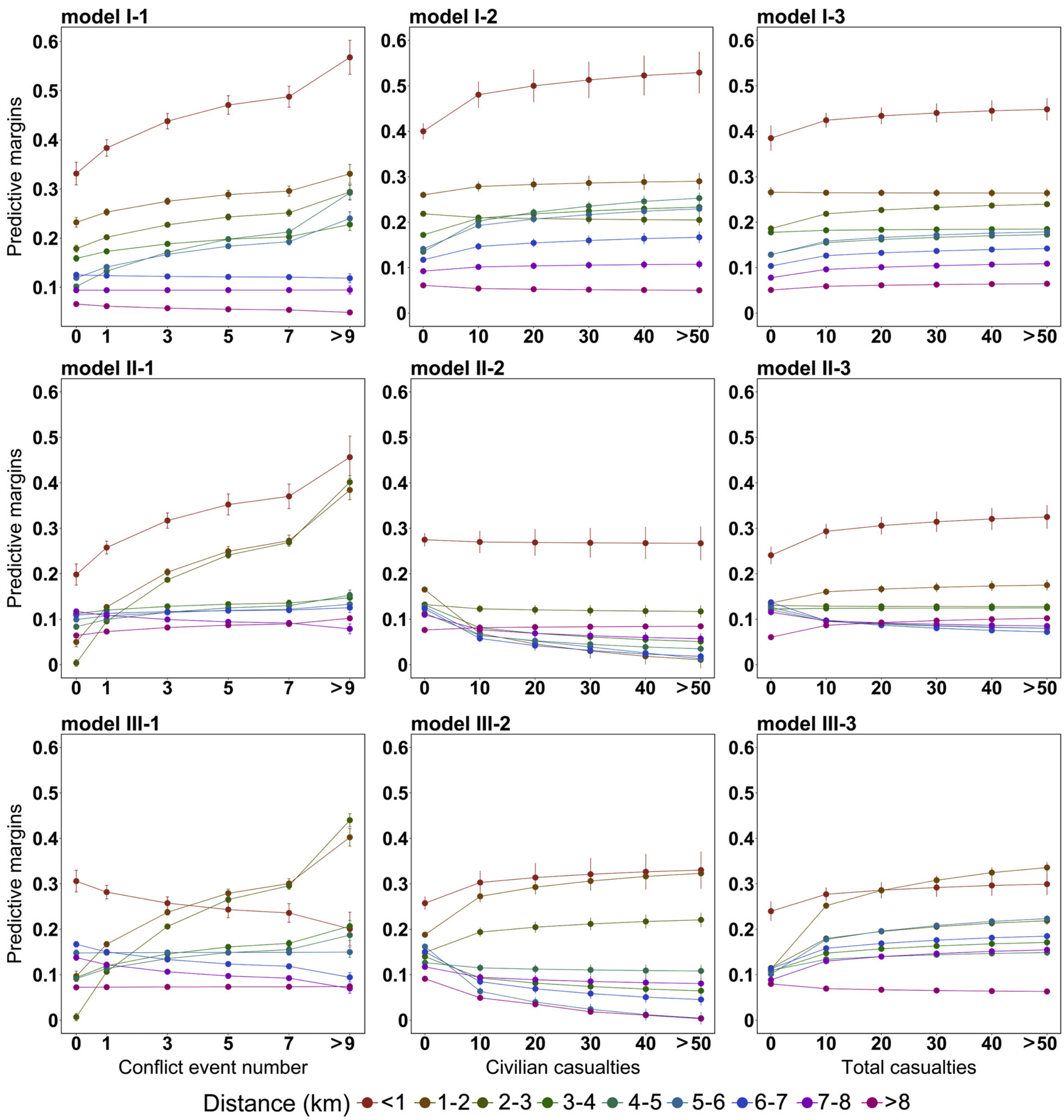

Fig. 4. Marginal effects of armed conflicts on agricultural land abandonment at different distances to conflicts, and for different numbers of conflict events, civilian casualties and total casualties, with 95% confidence intervals. Model I shows the marginal effects of the First Chechen War using logit model, model II uses fixed-effects model and model III uses random-effects model for the Second Chechen War.

that higher numbers of conflicts resulted in higher abandonment probabilities for agricultural lands within 3 km of conflicts (Fig. 4, model II-1). However, in the random-effects model, only agricultural lands that were within 1–5 km from conflicts had significantly higher abandonment probabilities when there were more conflicts (Fig. 4, model III-1). We also found a slight difference between our fixed-effects and random-effects model that included civilian casualties to explain land abandonment. More civilian casualties led to higher abandonment probabilities in the random-effects models (Fig. 4, model III-2) but not the fixed-effects models (Fig. 4, model II-2) for agricultural land that was within 3 km of conflicts. In general, casualties were positively linked to agricultural land abandonment in both models, but for some distances, the relationship was negative (Fig. 4, model II-3, III-3).

4. Discussion

We applied logistic and panel regression models to investigate the relationship between armed conflicts and agricultural land-use change in the northern Caucasus. We found that areas closer to armed conflicts, and areas with higher conflict intensity had higher rates of agricultural land abandonment. We also found higher re-cultivation rates of abandoned fields father away from conflicts in the post-conflict era, suggesting the long-lasting effects of the conflicts. While our methods did not allow to identify causal mechanism of armed conflicts directly, the patterns that we found are consistent with several direct and indirect causes of armed conflicts on agricultural land-use in the northern Caucasus.

We found that rates of abandonment were higher in areas that were closer to conflict events. During the First Chechen War, for example,

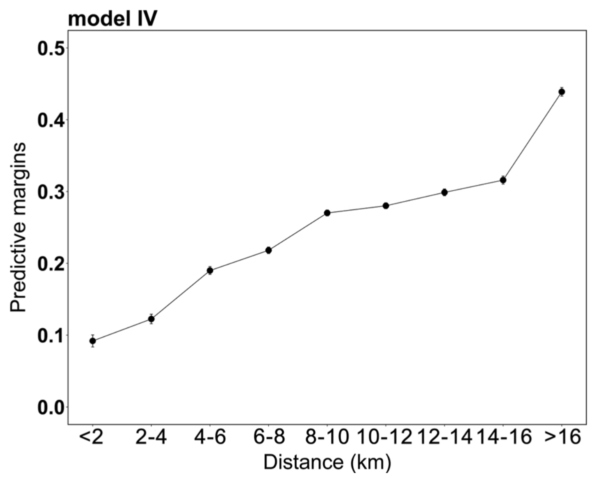

Fig. 5. Marginal effects of conflicts on agricultural re-cultivation at different distances from conflicts, with 95% confidence intervals.

agricultural land that was within 1 km of conflict had the highest agricultural land abandonment probability (predictive margins > 40%, Fig. 4). This finding is similar to the previous studies in Syria (Eklund et al., 2017) and Nagorno-Karabakh in the southern Caucasus (Baumann et al., 2015). It is likely that both displacement and casualties of former state and collective farmers in Chechnya and Ingushetia were important reasons (Sakwa, 2005; Witmer and O'Loughlin, 2011). Though no precise figure of internally displaced persons for Chechnya and Ingushetia exists, about 600,000 civilians had been forced from their homes as of the end of 1999 (USCR, 2000). The majority of the internally displaced persons were displaced within Chechnya and a substantial number of them (up to 250,000) fled to neighboring Ingushetia during 1999–2000 (Norwegian Refugee Council, 2001). In addition, the Chechen Wars limited access to agricultural inputs such as seeds, tools, irrigation and veterinary treatment. The unstable supply and the high cost of the agricultural inputs during wartime discouraged the usage of farmlands (ICRC, 2007). Lastly, widespread water and soil pollution impeded agricultural activities (Shakhtimirov et al., 2012).

We found that agricultural lands that experienced higher conflict intensity had higher rates of abandonment, but the predicted abandonment probability varied depending on how conflict intensity was measured. Among our three measures, the number of conflict events was positively correlated to agricultural land abandonment (Fig. 4), similar to what happened in paramilitary groups-dominated areas in Columbia (Sánchez-Cuervo and Aide, 2013). An explanation for this may be that farmers change their behaviors in response to frequent conflicts (Voors et al., 2012). To reduce the risks, farmers who experience multiple armed conflicts leave fields fallow and reduce agricultural activities (Arias et al., 2012). Persistent armed conflicts can also result in higher rates of poverty that prevent post-conflict agricultural reconstruction, such as in Rwanda (Serneels and Verpoorten, 2015). Interestingly, we found that the effects of conflict number on agricultural land abandonment differed somewhat between the First and the Second Chechen War. During the First Chechen War, the spatial spillover effects of conflict number reached as far as 6 km, but during the Second Chechen War it was only up to 3 km.

While the effects of the number of conflict events were fairly uniform, the effects of citizen casualties and total casualties on agricultural land abandonment rates were not (Fig. 4). Where farmlands were within 1 km of conflicts, more casualties resulted in more agricultural land abandonment. For farmlands that were more than 1 km afar, however, there was no general pattern of the influence of casualties on agricultural land abandonment. Two factors might explain this. First, casualty information, especially civilian casualties, may be less relevant to rural land-use change, because a large proportion of the civilian death in the northern Caucasus was caused by terrorist attacks (O'Loughlin et al., 2011). For instance, one of the events with the highest number of civilian casualties, the Beslan School attack in 2004, resulted in 334 deaths, including 156 children, but there was no prolonged military standoff. Second, though the UCDP is a state-of-art dataset, casualty estimates in the northern Caucasus may be incomplete (Weidmann, 2015).

We found in general little re-cultivation after the Chechen Wars, but the probability of re-cultivation was lowest near prior conflicts (Fig. 3,5). Very few studies have examined post-conflict agricultural land-use change (Baumann and Kuemmerle, 2016). We found long-lasting effects of armed conflicts on agricultural land-use in the northern Caucasus. Though a significant number of people has returned to Chechnya (e.g. 16,170 in 2003), either voluntarily or due to the shutdown of tent camps and other pressures in Ingushetia (European Commision, 2004), the re-cultivation rates in Chechnya were low. The limited investment in agriculture might be one of the reasons for low re-cultivation rates. After Russia's declaration of victory in 2009, the insurgency in Chechnya has been largely suppressed (Fig. 2). Concomitantly, large reconstruction funding from the Russian federal government was given to the new government (Russell, 2011; Zabyelina, 2013). However, the focus of the reconstruction efforts was to rebuild the capital Grozny, as well as infrastructure and the petroleum industry, while the agricultural sector received less attention (IDMC, 2013). The re-construction of transportation infrastructure might have though improved market access thereby encrouaging re-cultivation. However, we could not quantify such effects because no relibale information on road destruction during the wars and reconstruction thereafter, were available to us. Last, the lack of institutionalized land ownership remains a factor that limits agriculture in the northern Caucasus (Kolosov et al., 2017). Land disputes among farmers, ethnic groups, district municipalities, and big agricultural holdings often escalated into tensions and clashes (International Crisis Group, 2015; Koehler et al., 2017).

In addition to conflicts and their intensity, other variables influenced agricultural land abandonment as well, but the magnitudes of their coefficients were small. The effects of elevation, slope, and soil quality on abandonment were positive, while the distance to nearest settlement and nearest roads had negative effects in both the logistic and panel regression models (Table S1, and S3, Supplementary material). Unlike other Soviet regions where soil quality played an important role in agricultural land abandonment (Prishchepov et al., 2013), we found only small effects (Figure S1, Supplementary material). This may be partly due to relatively homogeneous soil quality in our study area, and partly due to the coarse resolution of the European Soil Database (1 km) that we used. The marginal effects of the distance to the nearest settlement showed that the farther from a settlement and a road, the less likely agricultural land abandonment during the First and the Second Chechen War (Figure S2 and S3, Supplementary material). This might be explained by the fact that a high number of conflict events occurred in the settlements and along the roads, especially along the Caucasian Federal Highway (O'Loughlin and Witmer, 2011).

Although we included variables that are commonly used to explain agricultural land-use change, we acknowledge that our variable selection was somewhat limited. For example, we did not include demographical variables in the models because no reliable and spatially detailed dataset was available to us for the northern Caucasus. We also did not include information on landmines, unexploded ordnance (UXO), and abandoned explosive ordnance (AXO) in our models because information where they are located and in what quantity remains limited in the northern Caucasus, especially in Chechnya (ICBL-CMC, 2018). For example, in 2010, Russia's Presidential Special Envoy to the Caucasus claimed that mines affected 14 km^2 of land in Chechnya (Russia Today, 2010) while Chechen officials and human rights organizations previously estimated that 165 km^2 of farmland was mined (Caucasian Knot, 2009). Last, allochthonous drivers such economic globalization may have influenced land-use change in the northern Caucasus. However, we presume that the influence of the global economy to regional economy was relatively even across the northern Caucasus and thus did not affect our within-region analyses.

Several sources of uncertainty in our models need mentioning. First, our agricultural land-use change map included some errors that may affect the marginal effects estimated. However, we presume that the mapping errors were randomly distributed and the influence of errors thus did not affect the comparison of the effect of armed conflict across different conflict distances. Second, during the First Chechen War, annual satellite imagery was not available when we finalized the maps, making it difficult to separate the effects of the collapse of the Soviet Union from the effects of the conflicts. Since then, “no-Payload Correction” Landsat TM imagery has been added to the USGS's data portal that has the potential to fill the data gap in the 1990s. Third, our analysis focused on one Landsat footprint only, and did not cover the entire Caucasus, which may have revealed land-use displacement. To the best of our knowledge, such effects were limited in the northern Caucasus though, partly because there are very few un-cultivated lands that are suitable for agricultural production near IDP camps and host families, and partly because of the scarce supply and high cost of agricultural inputs (Norwegian Refugee Council, 2001). Fourth, analysis at contiguous ownership and management units (fields) can provide an improved representation of landscape pattern over existing pixel-based models, yet field boundary is rarely available at a large scale (Sohl et al., 2017). We tested our models using the objects produced by Yin et al. (2018) as analysis unit and the results showed a similar pattern as that using pixel as analysis unit (Figure S4, Supplementary material). Fifth and last, spatial autocorrelation can lead to biased standard errors in models of land-use change. In our models, with a binary dependent variable and a large number of observations, we are not aware of an approach to efficiently add spatial lags. However, a number of features of our analysis limit the potential for spatially autocorrelated errors: a) we used 5% of the pixels, which should reduce spatial relationship between observations, b) we included a rich set of co-variables that minimized potential for spatial unobservables, and c) we included regional dummy and geolocation variables, which absorb potential unobserved variation for variables within each district.

In summary, we found a higher probability of agricultural land abandonment in areas closer to conflicts and with higher conflict intensity. Our study also highlighted the long-lasting legacy of the armed conflicts on land-use in that we found limited re-cultivation of abandoned agriculture in areas closer to the armed conflicts. This, however, does not mean that the reconstruction of the agricultural sector will not happen in the future. Our findings have important political and socio-economic implications. Understanding agricultural land-use change and identifying spatial and temporal patterns in war-torn areas provide references for post-conflict agricultural management thus supporting returning refugees, local farmers, and allow to redirect reconstruction funding more effectively. Overall, our study provides a better understanding of the Chechen Wars and agricultural land-use change in the northern Caucasus, which may be applicable when predicting the consequences of armed conflicts on land-use in other war-torn areas.

Declaration of interest

All co-authors have agreed with the contents of this manuscript and its submission to Global Environmental Change. The work presented is original work and is not being considered for publication elsewhere. Any research in the manuscript not carried out by the authors has been fully acknowledged. We are prepared to cover all publication costs should our article be accepted.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gloenvcha.2019.01.005.

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