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Localized versus wide-ranging effects of the post-Soviet wars in the Caucasus on agricultural abandonment

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ABSTRACT

Wars are frequent and can affect land use substantially, but the effects of wars can vary greatly depending on their characteristics, such as intensity or duration. Furthermore, the spatial scale of the effects can differ. The effects of wars may be localized and thus close to conflict locations if direct mechanisms matter most (e.g., abandonment because active fighting precludes farming), or wide-ranging, e.g., farther away from conflict locations, if indirect mechanisms predominate (e.g., no access to agricultural inputs). Our goal was to quantify how the very different wars in the Caucasus region during post-Soviet times most likely affected agricultural abandonment at different scales. We analyzed data on conflict locations plus Landsat-derived land-cover data from 1987 to 2015, and applied matching statistics, difference-in-differences estimators, and logistic panel regressions. We examined the localized versus wide-ranging effects of the different wars on permanent agricultural abandonment and inferred to direct and indirect mechanisms that may have resulted in agricultural abandonment. While permanent agricultural abandonment was overall surprisingly limited across the Caucasus, up to one third of abandonment was most likely related to the wars. Among the wars, the war in Chechnya was by far the most intense and longest, but its effect on abandonment was similar to the less intense and relatively short war in Abkhazia. 47 % and 45 % of agricultural abandonment was related to each war, respectively. The reason was that the effect of the war in Chechnya was more localized, and abandonment occurred near conflict locations, in contrast to Abkhazia, where the effect was wide-ranging and abandonment occurred farther away from conflict locations. In contrast, the war in South Ossetia showed no significant effect on abandonment, and the war in Nagorno-Karabakh had the surprising pattern that abandonment was higher where no war had occurred. For each of the wars, abandonment was predominately related to the nearest conflict locations, but in Abkhazia additional conflict locations within 10 km further increased the probability of abandonment. We infer that the direct mechanisms of the war such as bombing, and active fighting most likely resulted in a localized effect close to conflict locations in Chechnya and in Nagorno-Karabakh. However, in Nagorno-Karabakh subsidies for new settlers after the war, (i.e., a positive wide-ranging effect), potentially reduced the amount of abandonment there. In contrast, negative wide-ranging effects such as refugee movements and post-war restrictions on their return is related to broad-scale abandonment in Abkhazia. In summary, permanent agricultural abandonment was not necessarily higher in a war with a high overall intensity. Instead, the effect of a given war varied in scale, and was related to the relative importance of direct and localized versus indirect and wide-ranging mechanisms, including postwar events and policies, which is likely the case for other wars, too.

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1. Introduction

Wars can have strong and potentially long-lasting consequences on land use (Baumann and Kuemmerle, 2016), but their effects differ. On the one hand, settlements are often destroyed (Lubin and Saleem, 2019) and forests are cut when paramilitary groups are present or refugees escape to forests (Butsic et al., 2015; Nackoney et al., 2014; Sanchez-Cuervo and Aide, 2013). On the other hand, wars can result in the growth of settlements when they offer economic opportunity for refugees (Pech and Lakes, 2017; Wilson and Wilson, 2013) and forest cover can regrow when logging declines after rural populations are forcefully displaced (Sanchez-Cuervo and Aide, 2013). Similarly, wars often result in agricultural abandonment (Baumann et al., 2015; Sanchez-Cuervo and Aide, 2013; Yin et al., 2019), but can also increase agricultural activities to raise funds, which was the case in areas controlled by the Islamic State in Syria and Iraq (Eklund et al., 2017), or when refugees convert forests to cropland to increase production to remain self-employed (Maystadt et al., 2020). We focused on agricultural abandonment, because conflicts are often concentrated in agricultural areas (Baumann and Kuemmerle, 2016) and farming is crucial for food security, especially during wartime (Adelaja and George, 2019).

The difference in land-use outcomes among wars may be related to the characteristics of the wars (Gray and Martin, 2008). While some wars are of relatively low intensity, others have high numbers of conflict events and fatalities (Cook and Lounsbery, 2017). Similarly, some wars are short, while others continue for years (Gray and Martin, 2008). And regarding the type of war, some are conventional wars among nations, some are guerilla wars aiming to overthrow the government of one country, and others are wars for independence (Cook and Lounsbery, 2017). We assumed that higher intensity and longer duration of a war would result in more land-use changes, especially in more agricultural abandonment. However, the great variability in agricultural outcomes of different wars warrants a closer look at the characteristics of wars and the mechanisms via which they affect land use.

The different mechanisms that affect agricultural abandonment can be localized and direct or wide-ranging and indirect. Direct mechanisms resulting in agricultural abandonment include restrictions of farmers to access their fields because of active combat (The Halo Trust, 2014), the destruction of irrigation infrastructure (Özerdem and Roberts, 2012), the contamination of fields with land mines, or the killing of farmers (The Halo Trust, 2014). Indirect mechanisms include the disruption of transportation route and hence access to markets (Unruh and Shalaby, 2012), limits of agricultural input such as seeds, machines, and fertilizers (ICRC, 2007), or shortages of agricultural labor due to conscription for military service (Eklund et al., 2016; Temudo and Silva, 2012). Another set of indirect mechanisms affecting agricultural abandonment is related to refugee movements and forced displacement, often accompanied by uncertainty in land ownership (Betancur-Alarcón and Krause, 2020). In every war, both direct and indirect mechanisms likely affect agricultural abandonment, but their relative importance may vary among wars. Teasing apart which mechanism matters most is difficult though, because of a lack of data measuring them during wars.

One way to assess the relative importance of direct versus indirect mechanisms is to examine the distances, thus the spatial scale, at which individual conflict locations, i.e., the actual places where fighting occurred, affect agricultural abandonment. To be specific in naming, we refer to a single instance of organized violence of armed forces with at least one fatality as a 'conflict event' (Sundberg and Melander, 2013), the places where one or more conflict events occurred as 'conflict locations', the area around conflict locations at certain distances as 'area of all conflicts', and the combination of many conflict events at conflict locations during one or several years as a 'war'. The effects of direct mechanisms of war are presumably fairly local in scale. If direct mechanisms are most important, abandonment should be concentrated near conflict locations where active fighting took place. Indeed, for example in the case of the war in Chechnya, agricultural land closer to a conflict location was more likely to be abandoned, especially when the conflict intensity at that location was high (Yin et al., 2019). In contrast, indirect mechanisms are presumably more wide-ranging and if indirect mechanisms are more important, abandonment may occur anywhere within the area of all conflicts.

Quantifying the effect of a given war on agricultural abandonment, as well as the scale (e.g., distances) at which conflict locations matter, presents several methodological challenges. Indeed, some of the aforementioned differences in the reported effects of different wars on land use may reflect methodological limitations that biased results. When assessing the effect of a given war on land use, it is necessary to account for changes in land use that would have happened even without the war, and that requires both a valid non-conflict area for control and land-use information before and after the war. Assessments that lack such a control may not provide reliable estimates (Schutte and Donnay, 2014). Inferring the effect of a war by summarizing land use before and after the war in the area of all conflicts itself (e.g., Jaafar et al., 2015; Witmer and O'Loughlin, 2009), may result in biased outcomes, because observed changes may be due to other factors, such as droughts, or changes in markets. While it is not necessary nor possible to include all these factors explicitly when assessing the effect of a war, they need to be controlled for. One way, to compare land-use information before and after a war, is a difference-in-differences approach, which showed, for example, that forest loss after Colombia's peace agreement increased with the start of the ceasefire (Murillo-Sandoval et al., 2021; Prem et al., 2020). Again, valid non-conflict samples are needed to rule out the effect of other factors. Here, we propose a novel approach to assess the effects of wars that includes both a valid control group by using matching statistics and a difference-in-differences model (also known as before-after-control-impact (BACI)), to consistently estimate the effects of wars and to compare them (Plantinga, 2021; Wendland et al., 2015).

Assessing the effects of conflict events is similarly complicated because of the complex interaction of distance-to and intensity-of conflict locations. To disentangle these interactions requires making conflict locations the unit of analysis rather than a region or a municipality (Schutte and Donnay, 2014), as is typically done (Castro-Nunez et al., 2017; Negret et al., 2019; Prem et al., 2020). Studies that analyze the conflict location show that the distance to the nearest conflict location matters (Landholm et al., 2019; Yin et al., 2019), but they focused only on the nearest location, and did not consider the effects of all conflict locations and their combined effect on forest change or abandonment. However, we assumed that farmers may be more likely to abandon their fields if there are several conflict locations in the vicinity, and that their land-use decisions would not just depend on the nearest conflict location (Linke and O'Loughlin, 2015).

Our goal was to identify the effects of wars on permanent agricultural abandonment. Specifically, we were interested to separate the effect of a war in its entirety versus the effect of conflict locations and their intensity at different scales on agricultural abandonment, so that we could infer the relative importance of localized and direct versus wide-ranging and indirect mechanisms via which wars are related to agricultural abandonment. We focused on the major wars in the Caucasus, which all occurred since the late 1980s, but varied greatly in their characteristics, especially in overall intensity and duration.

Specifically, we had two objectives:

1. Assess the effects of all four wars together, and the effect of each war by itself on agricultural abandonment. We expected that a war with higher intensity and longer duration was related to more agricultural abandonment.
2. Assess the scale and the interaction of distance-to and intensity-of conflict locations on agricultural abandonment for all wars together and for each war by itself. We expected that abandonment was more likely when a) the nearest conflict location was closer, b) there were more conflict events or more fatalities at that location,

and c) there were additional conflict locations in the vicinity, especially locations with high numbers of events or fatalities.

The combination of the effects of wars in their entirety (objective 1) and the effects of near conflict locations (objective 2), provide an indication of the relative importance of indirect versus direct mechanisms. A war, in which indirect mechanisms are strong, would exhibit a strong overall effect (objective 1), but the effect is not concentrated near the conflict locations (objective 2). In contrast, a war in which direct mechanisms are most important would have a strong concentration of an effect near conflict locations (objective 2), irrespective of the strength of the overall effect of that war (objective 1). We expected that the relative importance of indirect versus direct mechanisms would differ among the wars in the Caucasus, but we did not make an *a priori* prediction in which way.

2. Methods

2.1. Study area and the wars in the Caucasus

Our study area encompassed parts of the Russian Federation (North Caucasus), Georgia, Armenia, and Azerbaijan (South Caucasus), with a total area of approximately 455,000 km^2 (Fig. 1). The study area included two major mountain ranges: the Greater Caucasus Mountain Range and the Lesser Caucasus Mountain Chain (Zazanashvili et al., 2012). In the Greater Caucasus the average elevation ranges from 500 to 3,000 m above sea level (a.s.l.) in the West and declines towards the Caspian Sea in the East (Volodicheva, 2002), peaking at 5,642 m a.s.l. at Mount Elbrus. Precipitation is highest in the coastal area close to the Black Sea, exceeding 2,000 mm per year (Zazanashvili et al., 1999). Elevation in the Lesser Caucasus ranges from 2,000–2,800 m a.s.l. in the West and 2,500–3,300 m a.s.l. in the South-East with the highest point being Mount Aragats (4,090 m a.s.l.) in Armenia (Volodicheva, 2002). The climate in the Lesser Caucasus is wet in its western part, but continental in the East and South-East (Zazanashvili et al., 1999).

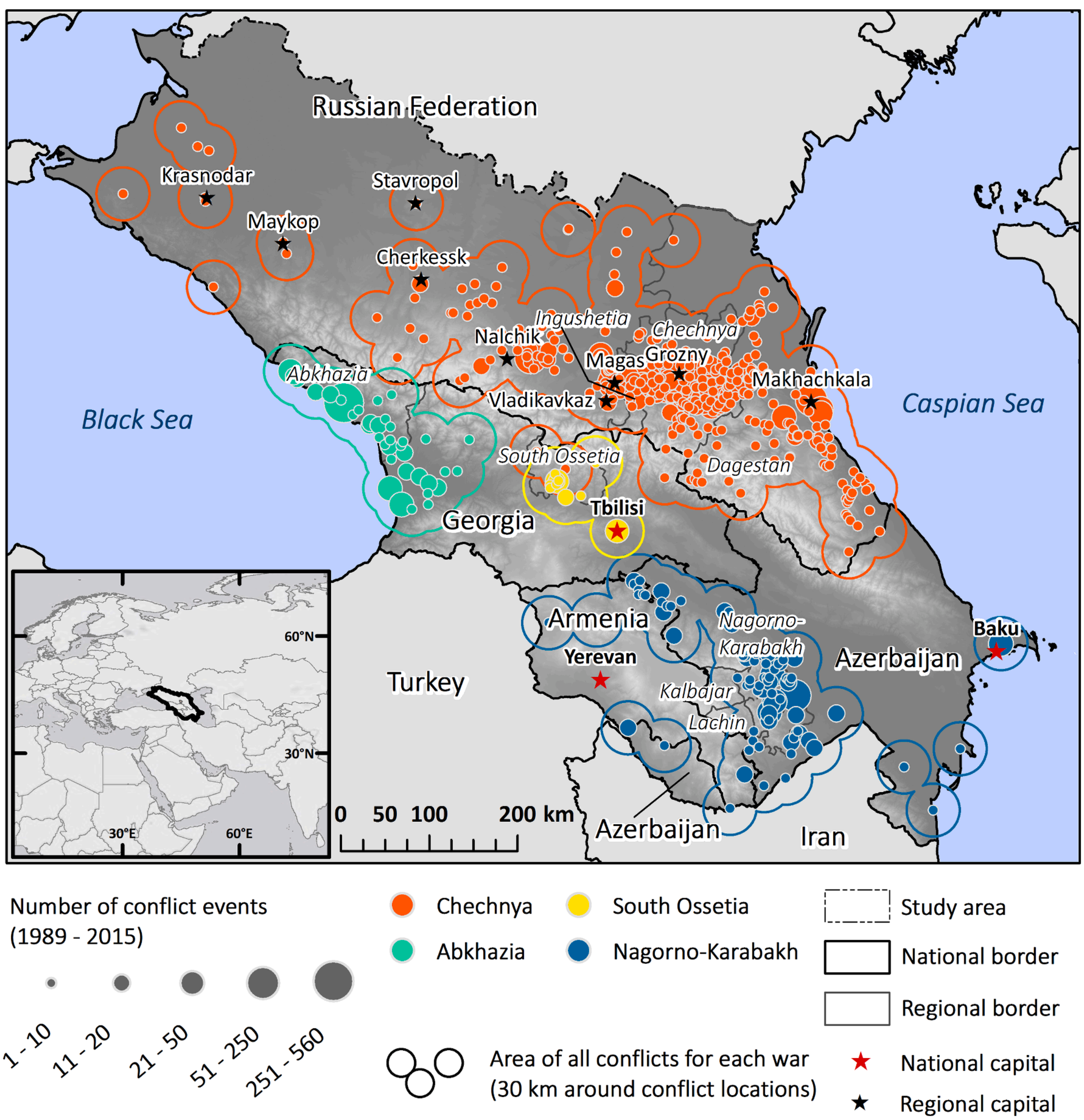

Fig. 1. Study area in the Caucasus and the four major wars in Chechnya, Abkhazia, South Ossetia, and Nagorno-Karabakh with the number of conflict events from 1989 to 2015 in each conflict location, and the area of all conflicts within a 5, 10, 20, and 30 km distance (only 30 km shown in map) (sources: conflict events: Uppsala Conflict Data Program (UCDP), elevation: Shuttle Radar Topography Mission (SRTM), outlines: Global Administrative Areas (GADM)).

Agriculture is important for employment, economic growth, poverty alleviation, and food security in all four countries (Holland, 2016; Welton et al., 2013). In the North Caucasus agriculture accounts for 22 % of the gross regional product (Holland, 2016). In Georgia, Armenia, and Azerbaijan, agricultural employment in 2015 was as high as 44 %, 35 %, and 36 %, respectively (World Bank Data, 2019). In the South Caucasus, small family farms practice agriculture as a combination of crop and fruit production as well as animal husbandry. Agriculture focuses on vegetables and crops such as wheat and potatoes, but also specialty products such as grapes and nuts (Ahouissoussi et al., 2014; Welton et al., 2013).

The region has a long history of ethnic tensions within and among countries, which were generally suppressed during the Soviet era, but started to rise with the dissolution of the Soviet Union. In the following, we refer to the regions of the different wars according to their names during the Soviet era, because those names are internationally best known. We used those names without any judgment on their post-Soviet changes in administrations. Similarly, we named conflict locations after the region in which the war they pertained to originated in. For example, we referred to conflict locations in the North Caucasus as 'Chechnya', even though some conflict locations were outside the territory of the Chechen Republic. Lastly, we analyzed all conflict events in a given region as one war, which means, for example, that we analyzed the first and the second Chechen war jointly.

After the collapse of the Soviet Union in 1991, tensions turned into full-scale wars in Chechnya (Russia), Abkhazia (Georgia), South Ossetia (Georgia), and Nagorno-Karabakh (Armenia and Azerbaijan) (Zürcher, 2007) (Table 1). The collapse of the political and economic system of the Soviet Union forced the countries to rebuild nations (Cornell, 2000; Freni, 2013; Lerman, 2001; Witmer and O'Loughlin, 2011). The Caucasus is a region of high ethnic diversity and strong national differences, as well as unequal living standards and economic disadvantages, which fueled the wars as did the dispute over territorial-status and independence (Freni, 2013; Kolossov and O'Loughlin, 2011; Nussberger, 2008; Yamskov, 1991), and Russia's continued interest in the region (Wiberg and Scherrer, 1999).

The Chechen wars were the most intense with an estimated 72,000

Table 1
Overview of the wars in the Caucasus[a].

War	Chechnya	Abkhazia	South Ossetia	Nagorno-Karabakh
Actors [1)]	State-based conflict: The Russian Federation vs Chechnya over Chechnya	State-based conflict: Georgia vs Abkhazia over Abkhazia	State-based conflict: Georgia vs South Ossetia over South Ossetia	State-based conflict: Armenia vs Azerbaijan over Nagorno-Karabakh
Duration [2)]	1. Chechen war 1994–1996 2. Chechen war 1999–2009	1992–1993 Five-Day war 2008	1991–1992 Five-Day war 2008	1988/ 1991–1994
Casualties [2)]	40,000	8,000–10,000	600–1,000	16,000
Refugees, internally displaced persons [2)]	greater than 700,000	240,000	42,000	1,000,000

[a] Sources: 1) Uppsala Conflict Data Program definition of a state-based armed conflict: "A state-based armed conflict is a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths in one calendar year. Comment: "State-based armed conflict" is also referred to as "armed conflict", as opposed to "non-state conflict", in which none of the warring parties is a government.", 2) Estimates based on De Waal, 2010; Pallin and Westerlund, 2009; Zürcher, 2007.

casualties (Zürcher, 2007). The first Chechen war (1994–1996) started three years after Chechnya declared independence from Russia and caused a wave of Chechens fleeing into neighboring Ingushetia and into the mountains. The capital Grozny was largely destroyed, and around 40,000 civilians were killed (Zürcher, 2007). The first Chechen war ended with the withdrawal of the Russian Army. Between the first and the second war (the second war lasted from 1999 to 2009), crime increased dramatically in Chechnya, state institutions were dismantled, and an Islamic governing body was established. The invasion of Dagestan and several bombings in Moscow by Islamic rebels from Chechnya triggered the Second Chechen War in 1999. Better prepared, the Russian military utilized heavy artillery and aerial bombing, which destroyed many settlements and cities. Attacks from rebels often targeted Russian offices, military, and police. Major operations ended in 2001, and in 2003 Chechnya presidential elections were held, overseen by Russia. The pro-Moscow Chechen government declared the end of the counter-terrorism operation in 2009, but clashes with militants remained in the North Caucasus (Holland et al., 2017). The second war displaced more than 700,000 people, many more than the first war, with the majority of the people not being able to return as quickly to their homes as after the first war (Zürcher, 2007).

In Abkhazia, fighting started in 1992 after Abkhazia declared itself independent from Georgia. In August 1992, approximately 5,000 Georgian soldiers entered Abkhazia (Zürcher, 2007), but by September 1993, Abkhazian forces gained control over Abkhazia, partly because Russia provided weapons and tanks (De Waal, 2010). Roughly 240,000 Georgians fled the region, and 8,000–10,000 people died, more than half of whom were civilians (De Waal, 2010; Zürcher, 2007). Russian peacekeepers were stationed in Abkhazia in July 1994, but further clashes occurred in 1997 and 2001 (Zürcher, 2007), and in 2008 during the Five-Day War between Georgia and Russia (Pallin and Westerlund, 2009). Traveling between Georgia and Abkhazia has been restricted since then (De Waal, 2010), and Georgian refugees have been largely barred from returning to Abkhazia. It is estimated that more than 50 % of Abkhazia's former population was forced to leave Abkhazia during the war, and only 10 % of the former population was able to return (Minority Rights Group International, 2018).

The war in South Ossetia started immediately after South Ossetia proclaimed itself independent from Georgia in 1991. In 1992, the Dagomys Agreement on South Ossetia was implemented but did not solve the underlying issues (De Waal, 2010), and did not prevent the Five-Day War in 2008, which primarily affected South Ossetia (Pallin and Westerlund, 2009). Compared to the other wars in the Caucasus, the South Ossetia war was less intense, but nevertheless 600–1,000 people died, and 42,000 Georgians became refugees (De Waal, 2010; Zürcher, 2007). Over time many civilians who lived within the conflict zone were allowed to cross the border between South Ossetia and Georgia.

In Nagorno-Karabakh, tensions started to rise in 1988 and intensified by 1991 when Armenia and Azerbaijan both declared independence and started the war over Nagorno-Karabakh after Karabakh declared independence from Azerbaijan (De Waal, 2010; Zürcher, 2007). By 1992, both sides were fighting with heavy weapons including rockets and tanks, causing widespread damage and destroying entire villages (De Waal, 2010). Once Armenia gained control over the district of Lachin, it was able to provide arms and supplies to Karabakh and occupied additional territory outside of Nagorno-Karabakh, which triggered a large wave of refugees to Azerbaijan in 1993. In 1994, the numbers of casualties increased steeply during a failed Azerbaijani defense of the Kalbajar region, and Armenia gained full or partial control over seven Azerbaijani regions. In total, the war in Nagorno-Karabakh caused the death of about 16,000 people and displaced 604,000 Azerbaijani citizens and 72,000 Armenians by the time a ceasefire was signed in May 1994 (Zürcher, 2007). Since then, ceasefire violations have occurred repeatedly (Bekiarova and Ilina, 2019). In September 2020, the conflict escalated in the "Six-Week War", with many Armenians fleeing land that was regained by Azerbaijan and a shift in territorial control (Smolnik et al., 2021).

2.2. Data

2.2.1. Remotely sensed land-cover change maps

To estimate agricultural abandonment from 1987 to 2015, we analyzed six land-cover maps for six target years: 1987, 1995, 2000, 2005, 2010, and 2015, derived in a previous study (Buchner et al., 2020). However, because of limited image availability, we had to aggregate satellite imagery from multiple years for each target year, that is from 1985-‘89, 1994-‘96, 1998–2002, 2003-‘07, 2008-‘12, and 2013-’15. For each target year, we mapped active cropland and nine other land-cover classes (coniferous forest, mixed forest, deciduous forest, barren, rangeland, built-up, wetlands, water, and snow and ice), from Landsat imagery covering the Caucasus region with 35 Landsat footprints. We compiled the 30-m resolution Landsat imagery into large-area image composites and classified them with the C5.0 decision tree classifier. The stable cropland class had a user’s accuracy of 71.3 % and a producer’s accuracy of 88.1 %, respectively (Buchner et al., 2020). We defined agricultural abandonment as an area that was classified as cropland in 1987, but as non-cropland in the following time steps. We mapped permanent agricultural abandonment based on five out of the six target years, starting in 1995, 2000, 2005, 2010, or 2015. For example, if a pixel was classified as cropland in 1987, 1995, and 2000, but as non-cropland in 2005, 2010, and 2015, the year of abandonment was 2000. We did not include pixels that were re-cultivated after abandonment in our analyses and focused on permanent abandonment only.

2.2.2. Conflict data and control variables

We analyzed conflict data provided by the Uppsala Conflict Data Program Georeferenced Event Dataset (UCDP GED, Version 19.1) (Högbladh, 2019; Sundberg and Melander, 2013). That dataset defines a conflict event as ‘an instance of organized violence with at least one fatality’. The UCDP dataset provides detailed information about the location and time, the number of events per location, and the best estimate of the number of total fatalities, both of which we analyzed as proxies for ‘conflict intensity’. We chose the UCDP dataset because it includes data back to 1989 and covers all four wars in their entirety. Although the actual duration of the wars did not last for the length of the study period, frequent ceasefire violations occurred after all four wars, and we included all conflict events and fatalities that occurred for the duration of the study period. We summarized the number of conflict events and the number of total fatalities for each location for five time periods corresponding to the target years of the land-cover maps (1989–1995, 1996–2000, 2001–2005, 2006–2010, and 2011–2015). In total, we analyzed 543 conflict locations with a total of 2633 conflict events from 1989 to 2015 (Fig. 1). We added a timeline of annual conflict locations to show that our five time periods were justified (Figure A1).

When estimating the effects of wars on agricultural abandonment, other factors that affect agricultural abandonment need to be accounted for (Adelaja and George, 2019; Yin et al., 2019). To do so, we included a suite of environmental, accessibility, and political-economic variables in our analyses (Table 2). We selected the ALOS Global Digital Surface Model (DSM) dataset to calculate elevation, slope, and aspect (Tadono et al., 2014; Takaku et al., 2014). Indeed, elevation-related variables may not only affect agricultural abandonment, but also conflict itself (Linke et al., 2017). We further extracted important variables such as maximum temperature and precipitation accumulation from the TerraClimate database (Abatzoglou et al., 2018) and topsoil carbon content from the FAO Harmonized World Soil Database (Wieder et al., 2014). Other variables captured accessibility to markets and infrastructure, such as distance to highways and settlements, which we derived from OpenStreetMap (OpenStreetMap contributors, 2017). We processed these data in Google Earth Engine (GEE, Gorelick et al., 2017). We

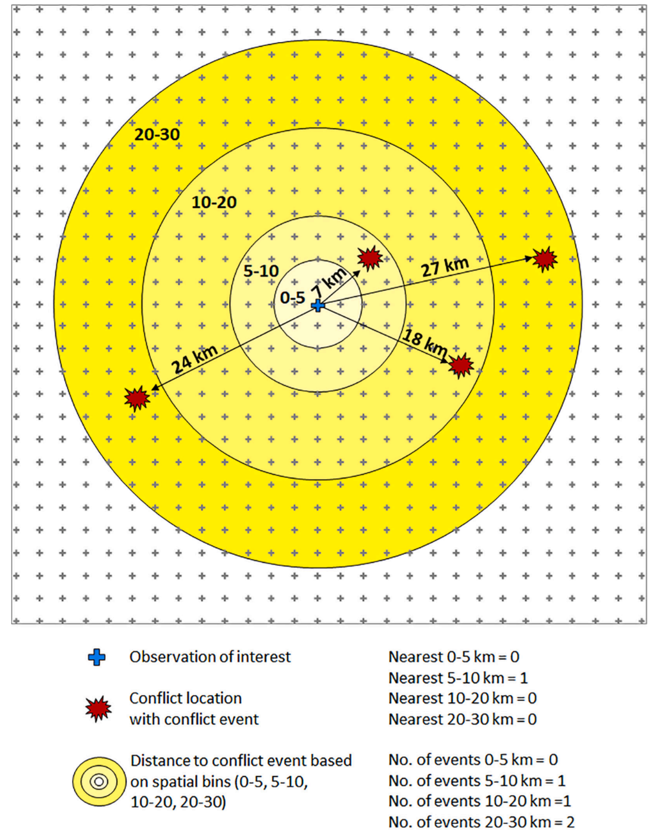

Fig. 2. Conceptual figure to assess the effect of conflict locations and the interaction between distance to and intensity thereof on agricultural abandonment. For the observation of interest, the nearest conflict location occurred within a distance of 5–10 km with a conflict intensity of one conflict event, and additional conflict locations occurred within a distance of 10–20 and 20–30 km with one conflict event each, which were all considered in the model.

further included information about the percentage of rangeland and forest within 100 m, because agriculture is more likely to be abandoned where growing conditions are marginal (Prishchepov et al., 2013). Finally, we added the country name as a categorical dummy variable to account for political and economic differences. We performed a natural log-transformation on the control variables and the conflict intensity measures to decrease the effects of scaling on the model.

2.3. Models

2.3.1. Sampling design and summary statistics

We sampled points on a 2-km point grid covering the entire study area. The 2-km resolution was a tradeoff between the need for a sufficient amount of samples and the computational costs for our statistical models and minimizing spatial autocorrelation between observations. We only analyzed grid points that were agriculture in 1987. This resulted in 40,220 points with a total of 241,320 observations over six target years. For each observation we calculated the distance to each conflict location within 30 km, and for each location, we summarized the number of events and the number of total fatalities for the five time periods (1989–1995, 1996–2000, 2001–2005, 2006–2010, and 2011–2015). We selected the 30-km threshold based on the size of our study region, and because two prior studies in the Caucasus region found that at distances beyond 30 km, conflict events had a negligible effect on agricultural abandonment (Baumann et al., 2015; Yin et al., 2019). For example, in Chechnya agricultural abandonment gradually decreased with increasing distance to conflict events. Almost 45 % of agriculture within 1 km of conflict events was abandoned compared to only 6 %

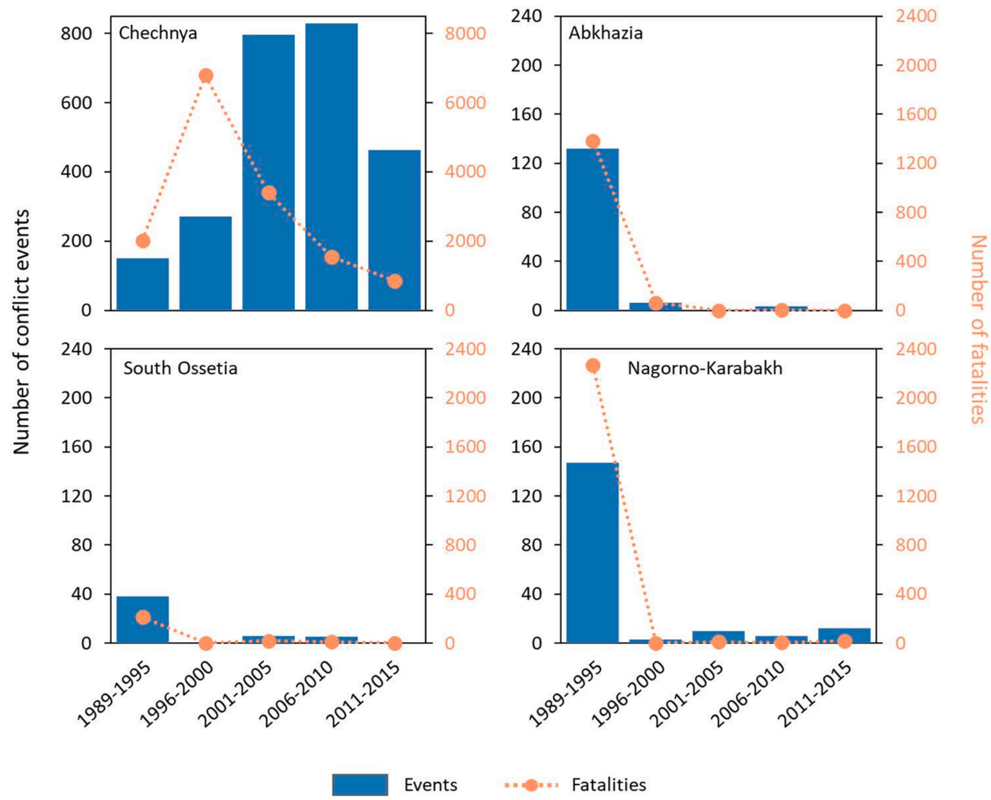

Fig. 3. Number of conflict events and number of total fatalities in the five time periods for Chechnya, Abkhazia, South Ossetia, and Nagorno-Karabakh. Note: y-axis ranges differ among wars (source: Uppsala Conflict Data Program).

Table 2
Variables included in the models to assess the effects of wars on agricultural abandonment.

	Variable	Unit	Period	Resolution	Source
Response variable	Agricultural change	1: agricultural abandonment, 0: non-abandonment	1987, 1995, 2000, 2005, 2010, 2015	30 m	Buchner et al., 2020
Conflict intensity variables	Number of conflict events, Number of total fatalities	count, count	annual numbers summarized for following time periods: 1987–1995, 1996–2000, 2001–2005, 2006–2010, 2011–2015	Point location	Sundberg and Melander, 2013
Control variables	Elevation, Slope, Aspect	m, degree, degree	Time-invariant	1 arc second (~30 m)	Tadono et al., 2014; Takaku et al., 2014
	Maximum temperature, Precipitation accumulation	°C, mm	1990, 1995, 2000, 2005, 2010, 2015	2.5 arc minutes (~4.6 km)	Abatzoglou et al., 2018
	Topsoil carbon content	%	Time-invariant	0.05 degree (~5.6 km)	Wieder et al., 2014
	Euclidean distance to highways, Euclidean distance to settlements	m, m	Time-invariant	–	OpenStreetMap contributors, 2017
	Percent rangeland within 100 m, Percent forest within 100 m	%, %	1987, 1995, 2000, 2005, 2010, 2015	30 m	Buchner et al., 2020
	Administrative boundaries of countries	dummy	Time-invariant	vector	Database of Global Administrative Areas (GADM version 3.6) (https://www.gadm.org)

when that distance was greater than 9 km (Yin et al., 2019). We binned the number of events and the number of total fatalities within distances of 0–5, 5–10, 10–20, and 20–30 km for each observation. In a final step, we extracted and added the value of the response variable (i.e., agricultural abandonment or not), and the control variables (Table 2).

To characterize the wars, we calculated summary statistics for each of the wars. First, we summarized the number of events and the number of fatalities from the UCDP dataset for each of the four wars – Chechnya, Abkhazia, South Ossetia, and Nagorno-Karabakh – for each of our five time periods. Second, we summed the number of conflict events for each land-cover class for each war and time period. We further calculated the amount of cropland around conflict events within 5 km, 5–10 km, 10–20 km, and 20–30 km distance for each war, to evaluate if Abkhazia's coastal geography may have affected where cropland abandonment occurred relative to conflicts, given that conflicts were often in urban areas, and most cities are located along the coast.

2.3.2. Effect of each war in its entirety on agricultural abandonment

Our first objective was to identify the effects of all wars together and of each war individually on agricultural abandonment. To do so, we first controlled for differences in observables between the area of all conflicts of each war and non-conflict area by creating valid treatment and control datasets via propensity score matching. We estimated the propensity score using a probit model (Guo and Fraser, 2014; Jones and Lewis, 2015), where the propensity score is the probability of an observation experiencing treatment, e.g., conflict event. Similar techniques have been successfully used to identify valid counterfactuals for analyzing the effects of armed conflicts on land use (Baumann et al., 2015), but also for assessing protected areas (Andam et al., 2008; Bragina et al., 2015, Jones and Lewis, 2015), and payments for environmental services (Arriagada et al., 2012).

Second, we controlled for unobservable or omitted-variable bias. To do this, we parameterized difference-in-differences models. These are regression models that compare observations in areas with and without treatment before and after the treatment event (Butsic et al., 2017; Dempsey and Plantinga, 2013). In this study, we compared agricultural abandonment in the area of all conflicts versus non-conflict area before and after conflict events. The estimated difference in abandonment from observations in the area of all conflicts and the non-conflict area is based solely on changes that took place between the two time periods. Therefore, time-invariant unobservable covariates, such as land-use history, do not bias the estimated effect (Wooldridge, 2002). We used the same observations as described in section 2.3.1. We defined the area of all conflicts as the area within four distances, i.e., 5, 10, 20, or 30 km, of all conflict locations that had conflict events for each war (Fig. 1). We excluded observations within a distance of 30–35 km to clearly separate the area of all conflicts from the non-conflict area. We then matched observations from the area of all conflicts and non-conflict area observations (i.e., observations greater than 35 km away from conflict events) based on our natural log-transformed control variables (Table 2) for 1995, 2000, 2005, and 2010 for each of the four distances. In total we had 16 matched datasets, i.e., matched observations from the area of all conflicts (5 km distance of all conflict events) with non-conflict area (greater than 35 km distance of all conflict events) for 1995, 2000, 2005, 2010 (= four datasets), and the same for 10 km, 20 km, and 30 km distance and all years (= 12 datasets). We removed observations from the area of all conflicts in the subsequent time step to avoid double labeling with non-conflict area observations. We merged all years for each distance of 5, 10, 20, and 30 km, resulting in four datasets.

We analyzed the datasets of all wars together to estimate the effect of wars on agricultural abandonment for the four distances (i.e., 5, 10, 20, 30 km) using the following difference-in-differences model (Wooldridge, 2002) for the entire Caucasus:

$$Y_{it} = \beta_1{*}Co_{it} + \beta_2{*}A_{it} + \beta_3{*}Co_{it}{*}A_{it} + \beta_4{*}Time_{it} + \beta_5{*}C_i + \beta_{6-9}{*}X_{it} + e_{it} \tag{1}$$

In this model, Y_{it} is agricultural abandonment (1), or not (0), for observation i in period t, Co_{it} is whether observation i in a time period t was in the area of all conflicts (1) or not (0), i.e., treated or not, A_{it} stands for after and indicates before (0), or after (1), conflict event, $Co_{it} * A_{it}$ is the interaction between treatment and A_{it} and indicates the effect of war, $Time_{it}$ is a categorical variable indicating time period, C_i indicates the country, X_{it} is the vector of control variables (i.e., maximum temperature, precipitation accumulation, percent rangeland, and percent forest), β_1-β_9 are the coefficients to be estimated, and e_{it} is the error term. The reason for including the $Time_{it}$ variable was to account for differences among years. For example, sparser media coverage in early years may have resulted in fewer conflict events in our database for those years, and those differences among years needed to be accounted for.

In the fixed effects model, time-invariant covariates (e.g., elevation) were not considered. The fixed effect model eliminates the assumption that unobserved variables are uncorrelated with the error term but relies on linear regression to fit a binary dependent variable. We chose the linear regression model because it allowed us to include fixed effects, such as time, in the model. We decided to not use a binary fixed effects model as including them is not recommended due to the incidental parameters problem, which results in biased estimates (Abrevaya, 1997; Greene, 2004). In total, we parameterized 4 regression models for the distances of 5, 10, 20, or 30 km from all the conflict locations. We used the 'margins' command in StataSE 16 to calculate the marginal effects of war on agricultural abandonment. Marginal effects represent the percentage point change in the probability an observation is abandoned due to war. In addition to the model for the entire Caucasus, we also modeled the effect of each individual war (equation A1 in the appendix).

2.3.3. Effects of distance to and intensity of conflict locations

To understand a) the effect of the nearest conflict locations, b) their intensities, and c) the effect of additional conflict locations farther away, on agricultural abandonment, we parameterized a logistic panel regression with random effects. In this model, we included a large number of interactions, and these interactions can be best interpreted through predicted probabilities, which is why we chose a random-effects model. We considered the nearest conflict location and its intensity, as well as additional conflict locations afar and their intensities, which is a novel contribution of our study (Fig. 2).

Our sample was again the point grid described in section 2.3.1. We identified the nearest conflict location within spatial bins (i.e., 0–5, 5–10, 10–20, and 20–30 km), and included the number of conflict events or fatalities at each location as two alternative measures of intensity.

Again, we included the natural log-transformed control variables (Table 2) to account for other factors related to agricultural abandonment. We estimated the following regression for the entire Caucasus.

$$\begin{aligned} Y_{it} = {} & \beta_1{*}nearest_{0-5kmit} + \beta_2{*}I_{0-5kmit} + \beta_3{*}nearest_{0-5kmit}{*}I_{0-5kmit} + \beta_4{*}nearest_{5-10kmit} + \beta_5{*}I_{5-10kmit} + \beta_6{*}nearest_{5-10kmit}{*}I_{5-10kmit} + \beta_7{*}nearest_{10-20kmit} \\ & + \beta_8{*}I_{10-20kmit} + \beta_9{*}nearest_{10-20kmit}{*}I_{10-20kmit} + \beta_{10}{*}nearest_{20-30kmit} + \beta_{11}{*}I_{20-30kmit} + \beta_{12}{*}nearest_{20-30kmit}{*}I_{20-30kmit} \\ & + \beta_{13}{*}C_i + \beta_{14-23}{*}X_{it} + \beta_{24}{*}C_iX_{it} + \beta_{25}{*}Year_{it} + e_{it} \end{aligned} \tag{2}$$

In this model, Y_{it} is agricultural abandonment (1), or not (0), for observation i in time period t, $nearest_{it}$ is a dummy variable indicating if conflict location within defined distances (0–5, 5–10, 10–20, and 20–30 km) is nearest (1), or not (0), I_{it} is the intensity measure, i.e., the number of conflict events or number of total fatalities, of observation i in time period t, $nearest_{it} * I_{it}$ is the interaction term between the distance dummy variable $nearest_{it}$ and the intensity measure I_{it}, C_i is a categorical variable indicating the country, X_{it} is the vector of control variables, $C_i * X_{it}$ is the interaction term between country and the control variables (e.g., elevation, maximum temperature, distance to settlements), $Year_{it}$ is a categorical variable indicating the time step, β_1-β_{25} are the coefficients to be estimated, and e_{it} is the error term. We ran one model with number of conflict events as the intensity measure and a second one with fatalities as the intensity measure. In addition to the model for the entire

Caucasus, we also modeled the effect of each individual war (equation A2 in the appendix).

The model provided coefficients indicating the relationship between conflict intensity at different distances and agricultural abandonment, and we calculated the predictive margins of conflict intensity and distance on agricultural abandonment for better interpretability. In addition, we predicted the probability of abandonment over a range of distances and conflict intensities to understand how abandonment changed due to both near and far conflict events and fatalities.

3. Results

3.1. Summary statistics of the four wars

The overall intensity, e.g., the number of all events and fatalities, differed greatly among the four wars. Chechnya had by far the highest total number of conflict events and the highest number of fatalities from 1989 to 2015 (Fig. 3), with seven times more conflict events and four times more fatalities than the other three wars combined. In Abkhazia, South Ossetia, and Nagorno-Karabakh the overall number of conflict events were much lower. The war in South Ossetia had the overall lowest number of conflict events and the lowest number of total fatalities (Fig. 3). The war in Chechnya was also by far the longest, and conflict events occurred throughout our entire study period, whereas conflict events in the other three wars mostly occurred before 1995.

Across the four wars, the majority of conflict events occurred in three land-cover classes: rangeland, cropland, and built-up areas (Figure A2). However, we found differences among wars and over time in terms of which land-cover class was most affected. In Chechnya, most conflict events occurred in built-up areas, cropland, or rangeland, but the number of events increased in built-up areas from 1996 until 2000 (Figure A2). In Abkhazia and South Ossetia, most conflict events occurred in cropland and urban areas, and in Nagorno-Karabakh in rangeland and cropland. We want to caution that urban areas are sometimes missed in land-cover classifications, especially in rural areas, where houses are mixed with gardens and other types of land cover. As a result, we may have underestimated the proportion of conflict events in urban areas. We further calculated the amount of cropland within different distances around conflict events to assess whether Abkhazia's coastal geography may have limited abandonment near conflicts sites but found that the percentage of cropland within different distance classes was similar for all wars (Figure A3).

3.2. Overall effect and effect of each individual war on agricultural abandonment

The results of our difference-in-differences models, which compared sample points within the entire area of conflicts with those outside (objective 1), showed that across the whole Caucasus, the area of all conflicts had higher probability of agricultural abandonment than non-conflict areas (Fig. 4, Table 3). For the whole Caucasus abandonment was significantly higher if the area of all conflicts was within 10 and 20 km of conflict locations, but the effect was highest when including areas within 30 km of conflict locations as the area affected by wars. Overall, 27 % of abandonment in the area of all conflicts of all wars was related to the wars within 30 km of conflict locations (Table 3). However, we also found clear differences among individual wars. First, while abandonment was significantly higher in the area of all conflicts in Chechnya and in Abkhazia, this was not the case in Nagorno-Karabakh and in South Ossetia. Second, the distances used to delineate the area of all conflicts mattered. In Chechnya, the probability of abandonment was highest in the area of all conflicts within 10 km of all conflict events. In contrast, in Abkhazia the probability of abandonment was only significantly higher within 20 or 30 km of all conflict events (Table 3). Please see the appendix for matching results (Table A1–A32), and full regression results (Table A33, A34).

3.3. Effects of distance to and intensity of conflict locations

Regarding the effects of conflict locations (objective 2), the results of the panel logit regression with random effects showed that conflict events nearby were more important than conflict events farther away when analyzing the whole Caucasus (Fig. 5). However, we found again clear differences among the four wars. In Chechnya and Nagorno-Karabakh, the probability of abandonment was highest, and significantly so, when the nearest conflict event occurred within 5 km, e.g., in the immediate surrounding of an observation with abandonment. The probability of abandonment was four times higher in Nagorno-Karabakh (28 %) than in Chechnya (6.7 %). In contrast, in Abkhazia, conflict events within a 10–20 km distance were related to the highest probability of abandonment (45 %), the highest probability of abandonment in any of the four wars. In South Ossetia, there were no significant differences in the effects of conflict events among different distances (Fig. 5).

Considering distance plus the intensity of the conflict locations, we found that the probability of abandonment was higher across the Caucasus when the conflict intensity was higher, especially when the nearest conflict event was within 5 km (Fig. 6). However, neither the number of conflict events nor the number of fatalities significantly increased the probability of abandonment within a given distance. The pattern that we found for the whole Caucasus also held true for Chechnya, but the probability of abandonment was generally lower there. In contrast, in Abkhazia, a low number of fatalities within 10–20 km resulted in a higher probability of abandonment than a higher number of fatalities

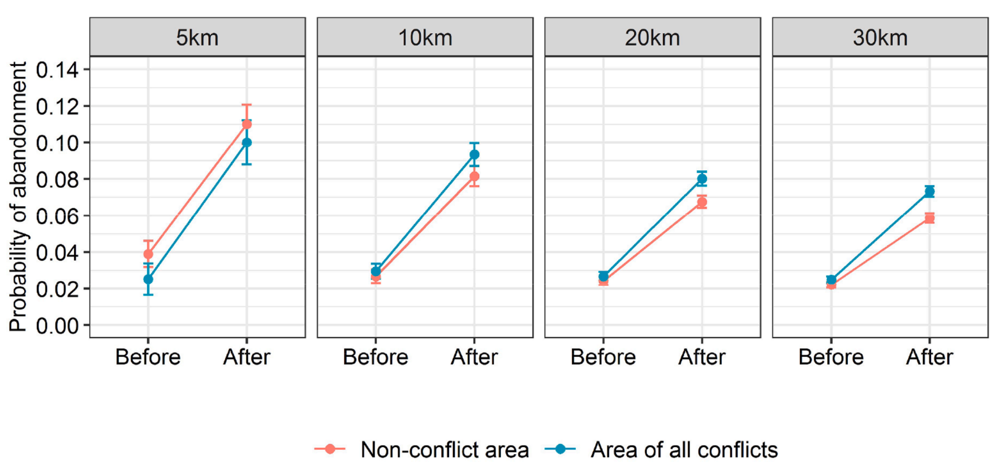

Fig. 4. Predictive margins with 95 % confidence intervals (CI) across the Caucasus before and after conflict events based on the area around all conflict locations with conflict events (5, 10, 20, and 30 km) that are considered as the area of all conflicts of all four wars on agricultural abandonment. The probability of abandonment was significantly higher in the area of all conflicts after the wars than before when the area of conflicts was defined as 10, 20, and 30 km, but showed no difference for 5 km.

Table 3
Marginal effects of conflict events on agricultural abandonment expressed as both percentage point change and percent change (based on agricultural abandonment in the area of all conflicts) depending on the distance from conflict locations with conflict events that delineated the area of all conflicts affected by a given war (5, 10, 20, and 30 km). A positive percentage point change indicates an increase in the probability of abandonment in the area of all conflicts compared to non-conflict area. Standard error in parentheses, *** p-value < 0.01, ** p-value < 0.05, * p-value < 0.1. Bold formatting indicates significant results.

War	Marginal effect (Percentage point change)				Marginal effect (Percent change in abandonment)			
	5 km	10 km	20 km	30 km	5 km	10 km	20 km	30 km
Whole Caucasus	0.3 (0.8)	**0.9 (0.4)****	**1.0 (0.3)*****	**1.2 (0.2)*****	4.4	**15.8**	**20.4**	**27.3**
Chechnya	1.2 (0.8)	**2.0 (0.5)*****	**1.7 (0.3)*****	**1.2 (0.2)*****	20.7	**46.5**	**47.2**	**38.7**
Abkhazia	2.0 (14.7)	11.7 (11.2)	**22.0 (5.8)*****	**18.4 (3.3)*****	3.14	19.0	**40.9**	**45.1**
South Ossetia	4.4 (5.6)	4.8 (3.5)	−1.5 (2.2	−0.9 (1.7)	48.9	50.0	−9.1	−7.1
Nagorno-Karabakh	−9.1 (3.8)	**−12.5 (2.0)*****	**−7.6 (1.1)*****	**−5.4 (0.8)*****	−66.0	**−64.4**	**−53.1**	**−39.7**

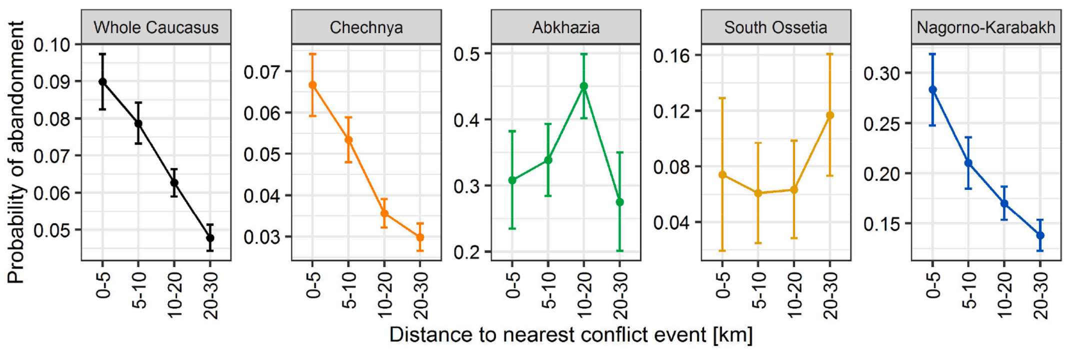

Fig. 5. Predictive margins of conflict events on agricultural abandonment when nearest conflict location with conflict events occurred at different distances (0–5, 5–10, 10–20, and 20–30 km) with 95 % confidence intervals. Note that y-axes differ among panels. For the whole Caucasus, Chechnya, and Nagorno-Karabakh the probability was highest when the conflict event was nearby, but the opposite was true for Abkhazia, and there were no differences among distances for South Ossetia.

closer or farther away. In Nagorno-Karabakh, the probability of abandonment was highest for the nearest distance (<5 km) and differed significantly from the 10–20 and 20–30 km distances when using fatalities, but neither the number of conflict events nor the number of fatalities was significantly different for a given distance. In South Ossetia, none of the distances and intensities differed significantly from each other (Fig. 6).

When we combined the nearest conflict location with conflict locations farther away plus their intensity measures, we found that adding conflict locations farther away to the ones nearby did not significantly increase the probability of abandonment for the whole Caucasus (Fig. 7). In Chechnya, additional conflict events and fatalities increased the probability of abandonment, but not significantly. However, in Abkhazia, adding conflict events in 5–10 km distance to the nearest events in 5 km distance, resulted in a significantly higher probability of abandonment. However, conflict locations farther away than 10 km did not increase the probability of abandonment, indicated by a flat line (Fig. 7). For South Ossetia and Nagorno-Karabakh, additional conflict locations did not increase the probability of abandonment at any distance. Please refer to the appendix for the overall regression results and for the individual war results (Table A35–A38).

Our panel logistic regression results also allowed us to assess the importance of other control variables for agricultural abandonment. The percentages of rangeland and of forest within a 100x100 m moving window were the two control variables with the greatest effect on the probability of agricultural abandonment, which matched our expectations. Where their values were highest (i.e., 100 %), the probability of abandonment reached 50 % and 26 %, respectively (Figure A4). The remaining control variables had only a small effect on the probability of agricultural abandonment (Figure A5), and we were surprised that topsoil carbon content was less important than we expected. However, lower values of topsoil carbon content had a slightly higher probability of abandonment, which is the direction of the effect that we had expected (Figure A5).

4. Discussion

We examined the effects of wars on the probability of agricultural abandonment at different spatial scales and found strong differences among the four wars in the Caucasus. First, we expected that a war with an overall high intensity and a long duration would be related to a high probability of agricultural abandonment, but we found that even a war with a relatively low intensity and short duration could be attributed to a high probability of abandonment, which surprised us. The reason for that was that the spatial scale of abandonment varied among wars, and thus the most intense war in Chechnya, where the effect was localized, had a similar outcome on abandonment as the less intense war in Abkhazia, where the effect was mostly wide-ranging. Second, we expected that fields near conflict locations would be more likely to be abandoned, especially if there were many conflict events or fatalities at that location, and our results generally confirmed this but with one important exception. In Chechnya and Nagorno-Karabakh conflict events within 5 km were related to the highest probability of abandonment, but in Abkhazia conflict events that were 10–20 km away had the highest probability. Third, we expected that abandonment would depend not only on the nearest conflict location, but also on whether there were additional conflict locations in the vicinity. We only found evidence for this in Abkhazia and only for additional conflict events up to 10 km, and not in the other three wars, so abandonment appeared to be largely related to only the nearest conflict location.

We found a clear relationship between wars and agricultural abandonment using a difference-in-differences model which allowed us to compare the area of all conflicts with a valid non-conflict area before and after the war. Across the Caucasus, 27 % of agricultural abandonment in the area of all conflicts was related to the wars. Among the four wars, we expected that the war in Chechnya would result in most abandonment, because the war was longest and most intense there. Indeed, 47 % of the abandonment in Chechnya was related to the war. However, roughly the same amount (45 %) was related to the war in

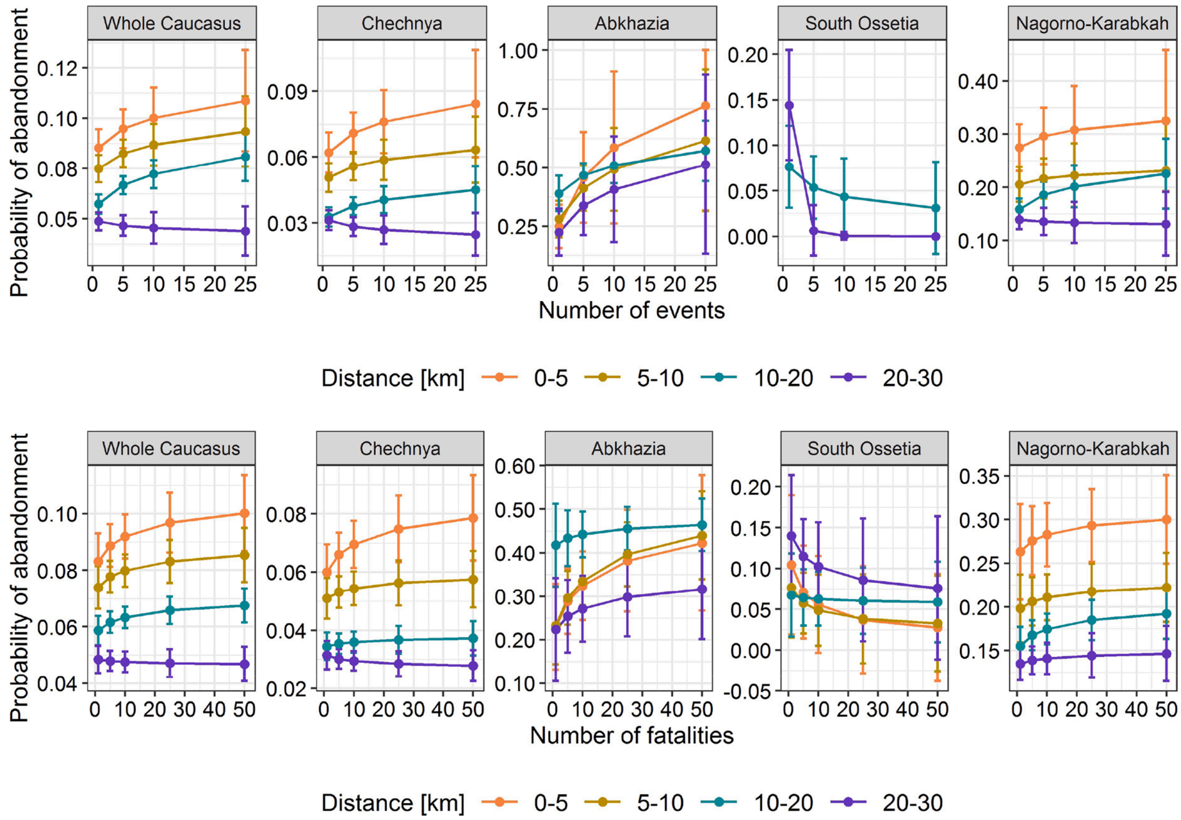

Fig. 6. The effects of distance to the nearest conflict location (line colors), and intensity at that conflict location (x-axes) on the probability of agricultural abandonment (y-axes) expressed as predicted margins with 95 % confidence intervals. Note that y-axes differ among panels. For the whole Caucasus, Chechnya, and Nagorno-Karabakh, the line representing effects of conflict events within 5 km (orange line) is on top, indicating that the nearest conflict event or fatalities resulted in a higher probability of abandonment. With an increasing number of conflict events (top row) or number of fatalities (bottom row), probability of abandonment increased. For South Ossetia the number of observations for conflict events at a distance of 0–5 and 5–10 km was very low and therefore not shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Abkhazia, despite its lower intensity and much shorter duration. Most likely the reason was that wars in Chechnya and Abkhazia affected abandonment at different spatial scales: in Chechnya, the war was rather localized, but in Abkhazia, it was wide-ranging.

Surprisingly, the war in Nagorno-Karabakh was not related to wide-ranging agricultural abandonment, despite intense combat and large numbers of refugees and internally displaced persons. This was especially unexpected because abandonment rates near major battle fields were as high as 60 % there (Baumann et al., 2015). However, our study differed in approach in that we analyzed the area around all conflict locations, not just near the largest battlefields, and we examined permanent abandonment up to 2015, not 2000.

When we assessed the interaction of distance to nearest conflict locations and additional conflict locations afar, we found that the probability of agricultural abandonment depended largely on the nearest conflict location. The distance to the nearest conflict location mattered most, supporting previous results for Chechnya only where the probability of abandonment decreased with an increasing distance to conflict location (Yin et al., 2019). The same pattern occurred in Darfur, where a higher number of violent events resulted in less agriculture, with a stronger effect when conflict events were close (Alix-Garcia et al., 2013). However, we found here that the pattern was different in Abkhazia, where conflict locations farther away were related to a higher probability of abandonment than conflict locations nearby. Furthermore, in Abkhazia, additional conflict locations farther away resulted in higher abandonment probability, once the nearest conflict locations were accounted for, but that was not the case in the other three wars.

We found that the four wars with different overall intensities resulted in quite different agricultural abandonment outcomes, which may be related to differences in the characteristics of the wars themselves, and in the relative importance of direct and indirect mechanisms via which the different wars were related to agricultural abandonment. In Chechnya, one reason why the war was fairly localized may be that attacks during the early years targeted mainly military, police, and governmental officials (O'Loughlin et al., 2011), thereby affecting farmers less, who continued farming because they relied on household-based agriculture as their main source of income (ICG, 2015). In later years, the war spread into neighboring republics, but was also concentrated in urban areas (O'Loughlin et al., 2011; O'Loughlin and Witmer, 2011). After the war, many people that were displaced, were relocated within Chechnya and to neighboring Ingushetia and Dagestan (UNHCR, 1996). A range of factors may have kept abandonment in Chechnya lower than expected and effects were fairly localized and concentrated near conflict locations, which indicates that in terms of agricultural abandonment direct mechanisms such as active combat, land mines, or the destruction of irrigation infrastructure were more important than indirect ones.

In Abkhazia, the effects of the war were wide-ranging and higher than expected. We suggest that this was mostly due to indirect mechanisms such as patterns of displacement, refugee movements combined with post-war travel restrictions. More than half of Abkhazia's pre-war population was forced to flee (Minority Rights Group International, 2008), which is a very high rate, and 240,000 people registered in Georgia in 2010 had fled Abkhazia and South Ossetia due to the wars there (IDMC, 2011). After the war, displaced people were not allowed to return to their homes (NRC/IDMC, 2015; UNHCR, 1996), except in one district in Abkhazia (i.e., Gali (IDMC, 2011)) where most displaced people returned to. The war also reduced tourism, even in regions that

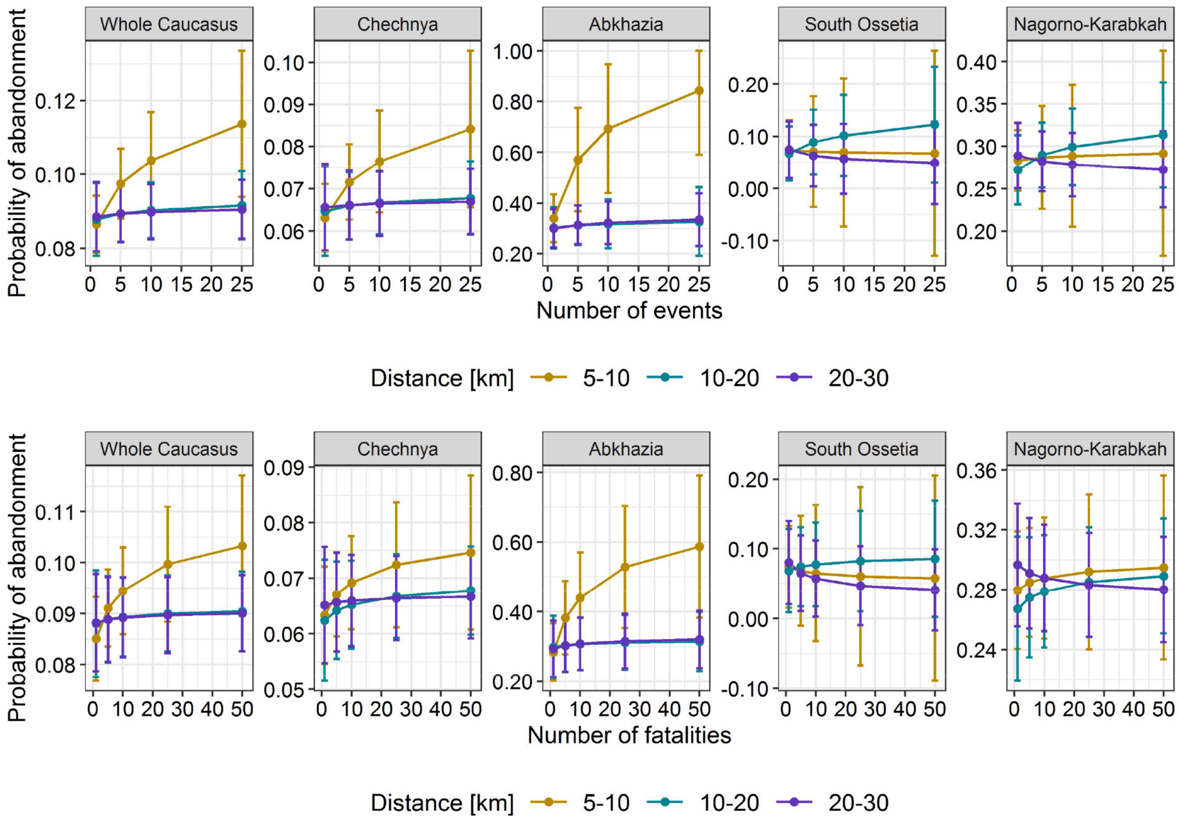

Fig. 7. The effects of additional conflict locations on the probability of agricultural abandonment (y-axes) that occurred when an agricultural area with a nearby conflict location (0–5 km) had additional conflict locations in farther distance (line colors), with varying intensity (x-axes). Note that y-axes differ among panels. The yellow line stems from the model that includes both nearby conflict locations plus secondary ones within 5–10 km (blue and purple accordingly for 10–20, and 20–30 km). For the whole Caucasus, Chechnya, and Abkhazia, the line representing effects of conflict events (top row) or fatalities (bottom row) within 5–10 km (yellow line) is increasing with a higher number of conflict events or number of fatalities, indicating that additional conflict events or fatalities in a 5–10 km distance increase the probability of abandonment. This is not the case for additional conflict events or fatalities in a 10–20 and 20–30 km distance. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

were afar from military activities (Radvanyi and Muduyev, 2007). Traveling from and to Abkhazia remained restricted, and the border between Abkhazia and Georgia was controlled by Russian troops (ICG, 2006). The indirect mechanisms such as the limited access, dispute over land, and impossibility of internally displaced persons to return to their homes most likely prevented the re-cultivation of agricultural fields (NRC/IDMC, 2015) and resulted in wide-ranging agricultural abandonment. This parallels the strong effects of post-WWII forced displacements in the Polish Carpathians, which resulted in widespread permanent abandonment and reforestation (Affek et al., 2021).

The effect of the war in South Ossetia on agricultural abandonment was insignificant. One reason could be the lower numbers of conflict events and fatalities compared to Chechnya, Abkhazia, and Nagorno-Karabakh, which may have resulted in a limited effect, but also meant that there were fewer observations in our models and hence larger confidence intervals. The same is true for agricultural abandonment, because large-scale agriculture production is less common and most of it is small-scale subsistence farming (Gerrits and Bader, 2016), we may have had fewer observations.

The war in Nagorno-Karabakh resulted in the largest number of internally displaced persons and refugees, but not in wide-ranging agricultural abandonment. Roughly 205,000 Azerbaijani fled Armenia and 247,000 Armenians fled Azerbaijan (Zürcher, 2007). The agricultural sector suffered heavy losses because of remaining mines and damaged irrigation systems (NRC/IDMC, 2005). However, Armenia provided economic support to the Karabakh region and subsidized wheat exports to Armenia (ICG, 2016, 2005), thereby fostering agriculture in the region. Since 2006, the de facto government of Nagorno-Karabakh established programs to support agriculture (ICG, 2017), and arranged long-term land rental agreements (ICG, 2017), which most likely prevented agricultural abandonment from becoming permanent. Although we found some evidence for localized effects, and hence direct mechanisms, indirect mechanisms such as large refugee movements were countered by other policy actions, especially agricultural subsidies and political interventions in the post-war period, that most likely limited the overall effect of the war on agricultural abandonment (ICG, 2017). In the fall of 2020, most of Nagorno-Karabakh reverted to Azerbaijani control, and will most likely affect agricultural land use again.

While agricultural abandonment was clearly related to wars, it was also surprising though that overall permanent abandonment in the Caucasus was low compared to post-soviet abandonment in other parts of Russia and Eastern Europe (Buchner et al., 2020). We had expected that the four wars on top of the collapse of the Soviet Union would have resulted in high agricultural abandonment, but abandonment was low, for example, compared to European Russia, where up to 56 % of pre-collapse agricultural land was abandoned (Alcantara et al., 2012; Baumann et al., 2011; Prishchepov et al., 2013). This means that although we found clear effects for two wars on cropland abandonment, and even though all four wars resulted in large numbers of fatalities and refugees, farming continued and farmers were resilient (Radvanyi and Muduyev, 2007). This was similar to what occurred in Colombia and Niger, where farmers continued cultivating their fields amid conflict (Adelaja and George, 2019; Arias et al., 2018), and land cover was relatively stable (but agriculture increased by 40 % in Colombia after the war (Murillo-Sandoval et al., 2021)). We caution though that there may have been cases of temporary stops of agricultural activities, so that fields were left fallow for several years, but then recultivated, that our land-cover classifications due to the necessary-six target years could not capture. Such recultivation may be especially likely in areas where displacement was temporary, and refugees were able to return.

Methodologically, our study contributes to recent efforts to link war and land-use changes by using quasi-experimental designs and accounting for differences in observables and controlling for omitted-variable bias (Landholm et al., 2019; Murillo-Sandoval et al., 2021; Prem et al., 2020; Yin et al., 2019). To detect the effects of wars despite relatively low overall abandonment, and to compare the effects of multiple wars, we used consistent methodology, included valid controls, i.e., matched sample unaffected by war, and controlled for other environmental drivers of agricultural abandonment. However, when interpreting our results, it is important to keep some limitations of our models in mind. One limitation is that media coverage in early years may have been sparse, leading to fewer reports of conflict events in our database, and we included a time variable in the models to assure that our results were not biased due to that. Further, our difference-in-differences approach may have missed abandonment before some of the conflict events occurred, because we mapped abandonment for the first time in 1995. Also, while we did include many control variables, we were not able to include information on numbers of internally displaced persons and refugees, land ownership, or economic welfare of farmers because such data were not available. Similarly, we only included permanent agricultural abandonment in our analysis, not fields that were abandoned temporarily and re-cultivated later. This means that we may have underestimated the effect of wars in areas with high re-cultivation rates such as Nagorno-Karabakh. Furthermore, our land-cover maps included some mapping errors, but we assumed that errors were randomly distributed across space. Spatial autocorrelation is another source of uncertainty and can lead to biased standard errors, which is why we spaced the points in our sampling grid afar from each other to minimize autocorrelation, and included a country dummy variable to account for potential unobserved variation.

In summary, the political instability after the collapse of the Soviet Union was followed by major wars in the Caucasus since 1991, and these wars differed greatly in intensity and duration, and how they were related to agricultural abandonment, especially the spatial scale at which these effects occurred. We found that higher intensity at the conflict location increased the probability of abandonment nearby, but additional conflict locations farther away were not as important as we expected. However, even a war with an overall low intensity can be related to widespread abandonment and indirect mechanisms of the war may be what may result in wide-ranging effects. Especially refugee movements, their ability to return, and other post-war policies, can shape the effects of wars on land use, and these mechanisms are not spatially concentrated near conflict locations but affect entire regions. More broadly, our results highlight that the effects of wars on land use are shaped by the dominance of either indirect or direct drivers that occur at different spatial scales. We were able to find these differences in spatial scales by analyzing multiple wars based on the same method, before comparing their effects. For future research on the effect of wars on land-use change, it will be of great value to standardize the modeling of the effects of wars on land use so that comparisons among studies are valid, and to add social surveys and qualitative interviews to identify the key drivers of abandonment with multiple methods.

CRediT authorship contribution statement

Johanna Buchner: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Van Butsic:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **He Yin:** Writing – review & editing. **Tobias Kuemmerle:** Writing – review & editing. **Matthias Baumann:** Writing – review & editing. **Nugzar Zazanashvili:** Writing – review & editing. **Jared Stapp:** Resources. **Volker C. Radeloff:** Conceptualization, Writing – review & editing, Funding acquisition, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Abatzoglou, J.T., Dobrowski, S.Z., Parks, S.A., Hegewisch, K.C., 2018. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Sci. Data 5, 170191. https://doi.org/10.1038/sdata.2017.191.

Abrevaya, J., 1997. The equivalence of two estimators of the fixed-effects logit model. Econ. Lett. 55, 41–43. https://doi.org/10.1016/S0165-1765(97)00044-X.

Adelaja, A., George, J., 2019. Terrorism and land use in agriculture: The case of Boko Haram in Nigeria. Land Use Policy 88, UNSP 104116. 10.1016/j.landusepol.2019.104116.

Affek, A.N., Wolski, J., Zachwatowicz, M., Ostafin, K., Radeloff, V.C., 2021. Effects of post-WWII forced displacements on long-term landscape dynamics in the Polish Carpathians. Landsc. Urban Plan. 214, 104164 https://doi.org/10.1016/j.landurbplan.2021.104164.

Ahouissoussi, N., Neumann, J.E., Srivastava, J.P., 2014. Building resilience to climate change in South Caucasus agriculture, No. 87601. The World Bank.

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

Alix-Garcia, J., Bartlett, A., Saah, D., 2013. The landscape of conflict: IDPs, aid and land-use change in Darfur. J. Econ. Geogr. 13, 589–617. https://doi.org/10.1093/jeg/lbs044.

Andam, K.S., Ferraro, P.J., Pfaff, A., Sanchez-Azofeifa, G.A., Robalino, J.A., 2008. Measuring the effectiveness of protected area networks in reducing deforestation. Proc. Natl. Acad. Sci. 105, 16089–16094. https://doi.org/10.1073/pnas.0800437105.

Arias, M.A., Ibáñez, A.M., Zambrano, A., 2018. Agricultural production amid conflict: Separating the effects of conflict into shocks and uncertainty. World Dev. https://doi.org/10.1016/j.worlddev.2017.11.011.

Arriagada, R.A., Ferraro, P.J., Sills, E.O., Pattanayak, S.K., Cordero-Sancho, S., 2012. Do Payments for Environmental Services Affect Forest Cover? A Farm-Level Evaluation from Costa Rica. Land Econ. 88, 382–399. https://doi.org/10.3368/le.88.2.382.

Baumann, M., Kuemmerle, T., Elbakidze, M., Ozdogan, M., Radeloff, V.C., Keuler, N.S., Prishchepov, A.V., Kruhlov, I., Hostert, P., 2011. Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. Land Use Policy 28, 552–562. https://doi.org/10.1016/j.landusepol.2010.11.003.

Baumann, M., Kuemmerle, T., 2016. The impacts of warfare and armed conflict on land systems. J. Land Use Sci. 11, 672–688. https://doi.org/10.1080/1747423X.2016.1241317.

Baumann, M., Radeloff, V.C., Avedian, V., Kuemmerle, T., 2015. Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict. Reg. Environ. Change 15, 1703–1716. https://doi.org/10.1007/s10113-014-0728-3.

Bekiarova, N., Ilina, A., 2019. Is the Peaceful Regulation of the Nagorno-Karabakh Conflict – Mission Possible? (SSRN Scholarly Paper No. ID 3332351). Social Science Research Network, Rochester, NY.

Betancur-Alarcón, L., Krause, T., 2020. Reaching for the Mountains at the End of a Rebelocracy: Changes in Land and Water Access in Colombia's Highlands During the Post-peace Agreement Phase. Front. Environ. Sci. 8 https://doi.org/10.3389/fenvs.2020.546821.

Bragina, E.V., Radeloff, V.C., Baumann, M., Wendland, K., Kuemmerle, T., Pidgeon, A.M., 2015. Effectiveness of protected areas in the Western Caucasus before and after the transition to post-socialism. Biol. Conserv. 184, 456–464. https://doi.org/10.1016/j.biocon.2015.02.013.
Buchner, J., Yin, H., Frantz, D., Kuemmerle, T., Askerov, E., Bakuradze, T., Bleyhl, B., Elizbarashvili, N., Komarova, A., Lewińska, K.E., Rizayeva, A., Sayadyan, H., Tan, B., Tepanosyan, G., Zazanashvili, N., Radeloff, V.C., 2020. Land-cover change in the Caucasus Mountains since 1987 based on the topographic correction of multi-temporal Landsat composites. Remote Sens. Environ. 248, 111967 https://doi.org/10.1016/j.rse.2020.111967.
Butsic, V., Baumann, M., Shortland, A., Walker, S., Kuemmerle, T., 2015. Conservation and conflict in the Democratic Republic of Congo: The impacts of warfare, mining, and protected areas on deforestation. Biol. Conserv. 191, 266–273. https://doi.org/10.1016/j.biocon.2015.06.037.
Butsic, V., Lewis, D.J., Radeloff, V.C., Baumann, M., Kuemmerle, T., 2017. Quasi-experimental methods enable stronger inferences from observational data in ecology. Basic Appl. Ecol. 19, 1–10. https://doi.org/10.1016/j.baae.2017.01.005.
Castro-Nunez, A., Mertz, O., Buritica, A., Sosa, C.C., Lee, S.T., 2017. Land related grievances shape tropical forest-cover in areas affected by armed-conflict. Appl. Geogr. 85, 39–50. https://doi.org/10.1016/j.apgeog.2017.05.007.
Cook, A.H., Lounsbery, M.O., 2017. Conflict Dynamics: A Comparative Framework, in: Conflict Dynamics, Civil Wars, Armed Actors, and Their Tactics. University of Georgia Press, pp. 11–28.
Cornell, S.E., 2000. Small Nations and Great Powers: A Study of Ethnopolitical Conflict in the Caucasus. RoutledgeCurzon, Richmond, Surrey, England.
De Waal, T., 2010. The Caucasus : An Introduction. Oxford University Press, Oxford.
Dempsey, J.A., Plantinga, A.J., 2013. How well do urban growth boundaries contain development? Results for Oregon using a difference-in-difference estimator. Reg. Sci. Urban Econ. 43, 996–1007. https://doi.org/10.1016/j.regsciurbeco.2013.10.002.
Eklund, L., Persson, A., Pilesjö, P., 2016. Cropland changes in times of conflict, reconstruction, and economic development in Iraqi Kurdistan. Ambio 45, 78–88. https://doi.org/10.1007/s13280-015-0686-0.
Eklund, L., Degerald, M., Brandt, M., Prishchepov, A.V., Pilesjö, P., 2017. How conflict affects land use: agricultural activity in areas seized by the Islamic State. Environ. Res. Lett. 12, 054004 https://doi.org/10.1088/1748-9326/aa673a.
Freni, S.J., 2013. Causes of Violent Conflict in the Caucasus since the Collapse of Communism. Inq. J. 5.
Gerrits, A.W.M., Bader, M., 2016. Russian patronage over Abkhazia and South Ossetia: implications for conflict resolution. East Eur. Polit. 32, 297–313. https://doi.org/10.1080/21599165.2016.1166104.
Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sens. Environ. Big Remotely Sensed Data: tools, applications and experiences 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031.
Gray, T., Martin, B., 2008. Comparing wars. J. Mil. Strateg, Stud, p. 10.
Greene, W., 2004. Fixed Effects and Bias Due to the Incidental Parameters Problem in the Tobit Model. Econom. Rev. 23, 125–147. https://doi.org/10.1081/ETC-120039606.
Guo, S., Fraser, M.W., 2014. Propensity Score Analysis, Second. ed, Advanced Quantitative Techniques in the Social Sciences. SAGE Publications, Inc.
Högbladh, S., 2019. UCDP GED Codebook version 19.1. Department of Peace and Conflict Research. Uppsala University.
Holland, E.C., 2016. Economic Development and Subsidies in the North Caucasus. Probl. Post-Communism 63, 50–61. https://doi.org/10.1080/10758216.2015.1067750.
Holland, E.C., Witmer, F.D.W., O'Loughlin, J., 2017. The decline and shifting geography of violence in Russia's North Caucasus, 2010–2016. Eurasian Geogr. Econ. 58, 613–641. https://doi.org/10.1080/15387216.2018.1438905.
ICG, 2005. Nagorno-Karabakh: Viewing the Conflict from the Ground (Europe Report No. 166).
ICG, 2015. North Caucasus: The Challenges of Integration (IV): Economic and Social Imperatives (Europe Report No. No 237).
ICG, 2016. Isolation of Post-Soviet Conflict Regions Narrows the Road to Peace [WWW Document]. Refworld. URL https://www.refworld.org/docid/5836e9143.html (accessed 4.3.20).
ICG, 2006. Abkhazia Today (Europe Report No. 176).
ICG, 2017. Nagorno-Karabakh's Gathering War Clouds (Europe Report No. No 244). Brussels.
ICRC, 2007. Farming through conflict (No. T2007 93/ 002 10/ 2007 2000). ICRC Economic Security Unit.
IDMC, 2011. Internal Displacement - Global Overview of Trends and Developments in 2010. Internal Displacement Monitoring Centre, Norwegian Refugee Council, Geneva, Switzerland.
Jaafar, H.H., Zurayk, R., King, C., Ahmad, F., Al-Outa, R., 2015. Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin. Int. J. Water Resour. Dev. 31, 436–449. https://doi.org/10.1080/07900627.2015.1023892.
Jones, K.W., Lewis, D.J., 2015. Estimating the Counterfactual Impact of Conservation Programs on Land Cover Outcomes: The Role of Matching and Panel Regression Techniques. PLOS ONE 10, e0141380.
Kolossov, V., O'Loughlin, J., 2011. After the Wars in the South Caucasus State of Georgia: Economic Insecurities and Migration in the "De Facto" States of Abkhazia and South Ossetia. Eurasian Geogr. Econ. 52, 631–654. https://doi.org/10.2747/1539-7216.52.5.631.
Landholm, D.M., Pradhan, P., Kropp, J.P., 2019. Diverging forest land use dynamics induced by armed conflict across the tropics. Glob. Environ. Change 56, 86–94. https://doi.org/10.1016/j.gloenvcha.2019.03.006.
Lerman, Z., 2001. Agriculture in transition economies: from common heritage to divergence. Agric. Econ. 26, 95–114. https://doi.org/10.1111/j.1574-0862.2001.tb00057.x.
Linke, A.M., O'Loughlin, J., 2015. Reconceptualizing, Measuring, and Evaluating Distance and Context in the Study of Conflicts: Using Survey Data from the North Caucasus of Russia. Int. Stud. Rev. 17, 107–125. https://doi.org/10.1111/misr.12207.
Linke, A.M., Witmer, F.D.W., Holland, E.C., O'Loughlin, J., 2017. Mountainous Terrain and Civil Wars: Geospatial Analysis of Conflict Dynamics in the Post-Soviet Caucasus. Ann. Am. Assoc. Geogr. 107, 520–535. https://doi.org/10.1080/24694452.2016.1243038.
Lubin, A., Saleem, A., 2019. Remote sensing-based mapping of the destruction to Aleppo during the Syrian Civil War between 2011 and 2017. Appl. Geogr. 108, 30–38. https://doi.org/10.1016/j.apgeog.2019.05.004.
Maystadt, J.-F., Mueller, V., Hoek, J.V.D., van Weezel, S., 2020. Vegetation changes attributable to refugees in Africa coincide with agricultural deforestation. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ab6d7c.
Minority Rights Group International, 2008. State of the World's Minorities 2008 -. Georgia/Abkhazia and South Ossetia.
Minority Rights Group International, 2018. World Directory of Minorities and Indigenous Peoples - Nagorny Karabakh (unrecognised state).
Murillo-Sandoval, P.J., Gjerdseth, E., Correa-Ayram, C., Wrathall, D., Van Den Hoek, J., Dávalos, L.M., Kennedy, R., 2021. No peace for the forest: Rapid, widespread land changes in the Andes-Amazon region following the Colombian civil war. Glob. Environ. Change 69, 102283. https://doi.org/10.1016/j.gloenvcha.2021.102283.
Nackoney, J., Molinario, G., Potapov, P., Turubanova, S., Hansen, M.C., Furuichi, T., 2014. Impacts of civil conflict on primary forest habitat in northern Democratic Republic of the Congo, 1990–2010. Biol. Conserv. 170, 321–328. https://doi.org/10.1016/j.biocon.2013.12.033.
Negret, P.J., Sonter, L., Watson, J.E.M., Possingham, H.P., Jones, K.R., Suarez, C., Ochoa-Quintero, J.M., Maron, M., 2019. Emerging evidence that armed conflict and coca cultivation influence deforestation patterns. Biol. Conserv. 239, 108176 https://doi.org/10.1016/j.biocon.2019.07.021.
NRC/IDMC, 2005. Profile of Internal Displacement: Azerbaijan [WWW Document]. Refworld. URL https://www.refworld.org/docid/3ae6a6250.html (accessed 4.3.20).
NRC/IDMC, 2015. Global Overview 2015: People internally displaced by conflict and violence - Europe, The Caucasus and central Asia [WWW Document]. Refworld. URL https://www.refworld.org/docid/55a617634.html (accessed 4.3.20).
Nussberger, A., 2008. The "Five-Day War" in Court Russia, Georgia, and International Law. Osteuropa 58, 19–39.
O'Loughlin, J., Holland, E.C., Witmer, F.D.W., 2011. The Changing Geography of Violence in Russia's North Caucasus, 1999–2011: Regional Trends and Local Dynamics in Dagestan, Ingushetia, and Kabardino-Balkaria. Eurasian Geogr. Econ. 52, 596–630. https://doi.org/10.2747/1539-7216.52.5.596.
O'Loughlin, J., Witmer, F.D.W., 2011. The Localized Geographies of Violence in the North Caucasus of Russia, 1999–2007. Ann. Assoc. Am. Geogr. 101, 178–201. https://doi.org/10.1080/00045608.2010.534713.
OpenStreetMap contributors, 2017. OpenStreetMap [WWW Document]. URL www.openstreetmap.org.
Özerdem, A., Roberts, R., 2012. The Impact of Conflict on Agriculture and Post-conflict Reconstruction Challenges. In: Özerdem, A., Roberts, R. (Eds.), Challenging Post-Conflict Environments: Sustainable Agriculture. Taylor & Francis Group, London, UNITED KINGDOM.
Pallin, C.V., Westerlund, F., 2009. Russia's war in Georgia: lessons and consequences. Small Wars Insur. 20, 400–424. https://doi.org/10.1080/09592310902975539.
Pech, L., Lakes, T., 2017. The impact of armed conflict and forced migration on urban expansion in Goma: Introduction to a simple method of satellite-imagery analysis as a complement to field research. Appl. Geogr. 88, 161–173. https://doi.org/10.1016/j.apgeog.2017.07.008.
Plantinga, A.J., 2021. Recent Advances in Empirical Land-Use Modeling. Annu. Rev. Resour. Econ. 10.1146/annurev-resource-100620-045839.
Prem, M., Saavedra, S., Vargas, J.F., 2020. End-of-conflict deforestation: Evidence from Colombia's peace agreement. World Dev. 129, 104852 https://doi.org/10.1016/j.worlddev.2019.104852.
Prishchepov, A.V., Müller, D., Dubinin, M., Baumann, M., Radeloff, V.C., 2013. Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy 30, 873–884. https://doi.org/10.1016/j.landusepol.2012.06.011.
Radvanyi, J., Muduyev, S.S., 2007. Challenges Facing the Mountain Peoples of the Caucasus. Eurasian Geogr. Econ. 48, 157–177. https://doi.org/10.2747/1538-7216.48.2.157.
Sanchez-Cuervo, A.M., Aide, T.M., 2013. Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas. Ecosphere 4, 1–21. https://doi.org/10.1890/ES13-00207.1.
Schutte, S., Donnay, K., 2014. Matched wake analysis: Finding causal relationships in spatiotemporal event data. Polit. Geogr. 41, 1–10. https://doi.org/10.1016/j.polgeo.2014.03.001.
Smolnik, F., Alieva, L., Shirinian, T., O'Loughlin, J., Toal, G., Bakke, K.M., 2021. Local Dimensions of the Nagorno-Karabakh Conflict. Cauc. Anal. Dig. CAD 121. https://doi.org/10.3929/ethz-b-000489488.
Sundberg, R., Melander, E., 2013. Introducing the UCDP Georeferenced Event Dataset. J. Peace Res. 50, 523–532. https://doi.org/10.1177/0022343313484347.
Tadono, T., Ishida, H., Oda, F., Naito, S., Minakawa, K., Iwamoto, H., 2014. Precise Global DEM Generation by ALOS PRISM. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. 4, 71–76. https://doi.org/10.5194/isprsannals-II-4-71-2014.

Takaku, J., Tadono, T., Tsutsui, K., 2014. Generation of High Resolution Global DSM from ALOS PRISM. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. 4, 243–248. https://doi.org/10.5194/isprsarchives-XL-4-243-2014.
Temudo, M.P., Silva, J.M.N., 2012. Agriculture and forest cover changes in post-war Mozambique. J. Land Use Sci. 7, 425–442. https://doi.org/10.1080/1747423X.2011.595834.
The Halo Trust, 2014. 25 years of getting mines out of the ground, for good. (Donor Report 2014). The Halo Trust, Dumfries, United Kingdom.
UNHCR, T.U.R.A.U., 1996. UNHCR publication for CIS Conference (Displacement in the CIS) - Conflicts in the Caucasus.
Unruh, J., Shalaby, M., 2012. A volatile interaction between peacebuilding priorities: road infrastructure (re)construction and land rights in Afghanistan. Prog. Dev. Stud. 12, 47–61. https://doi.org/10.1177/146499341101200103.
Volodicheva, N., 2002. The Caucasus. In: Shahgedanova, M. (Ed.), The Physical Geography of NorThern Eurasia. Oxford University Press, Oxford, New York, pp. 350–376.
Welton, G., Asatryan, A.A., Jijelava, D., 2013. Comparative analysis of agriculture in the South Caucasus. UNDP Georgia, Tbilisi, Georgia.
Wendland, K.J., Baumann, M., Lewis, D.J., Sieber, A., Radeloff, V.C., 2015. Protected Area Effectiveness in European Russia: A Postmatching Panel Data Analysis. Land Econ. 91, 149–168. https://doi.org/10.3368/le.91.1.149.
Wiberg, H., Scherrer, C. (Eds.), 1999. Ethnicity and Intra-state Conflict. Ashgate, Aldershot, Hants, England.
Wieder, W.R., Boehnert, J., Bonan, G.B., Langseth, M., 2014. Regridded Harmonized World Soil Database v1.2. ORNL DAAC.
Wilson, S.A., Wilson, C.O., 2013. Modelling the impacts of civil war on land use and land cover change within Kono District, Sierra Leone: a socio-geospatial approach. Geocarto Int. 28, 476–501. https://doi.org/10.1080/10106049.2012.724456.
Witmer, F.D.W., O'Loughlin, J., 2009. Satellite Data Methods and Application in the Evaluation of War Outcomes: Abandoned Agricultural Land in Bosnia-Herzegovina After the 1992–1995 Conflict. Ann. Assoc. Am. Geogr. 99, 1033–1044. https://doi.org/10.1080/00045600903260697.
Witmer, F.D.W., O'Loughlin, J., 2011. Detecting the Effects of Wars in the Caucasus Regions of Russia and Georgia Using Radiometrically Normalized DMSP-OLS Nighttime Lights Imagery. GIScience Remote Sens. 48, 478–500. https://doi.org/10.2747/1548-1603.48.4.478.
Wooldridge, J.M., 2002. Econometric Analysis of Cross Section and Panel Data, second. ed. MIT Press, Cambridge, Massachusetts.
World Bank Data, 2019. Employment in agriculture (% of total employment) (modeled ILO estimate) | Data [WWW Document]. World Bank Data. URL https://data.worldbank.org/indicator/sl.agr.empl.zs?end=2018&start=2018&view=map (accessed 5.24.19).
Yamskov, Anatoly.N., 1991. Ethnic conflict in the Transcausasus. Theory Soc. 20, 631–660. https://doi.org/10.1007/BF00232663.
Yin, H., Butsic, V., Buchner, J., Kuemmerle, T., Prishchepov, A.V., Baumann, M., Bragina, E.V., Sayadyan, H., Radeloff, V.C., 2019. Agricultural abandonment and re-cultivation during and after the Chechen Wars in the northern Caucasus. Glob. Environ. Change 55, 149–159. https://doi.org/10.1016/j.gloenvcha.2019.01.005.
Zazanashvili, N., Gagnidze, R., Nakhutsrishvili, G., 1999. Main types of vegetation zonation on the mountains of the Caucasus. Acta Phytogeogr. Suec. 85, 7–16.
Zazanashvili, N., Garforth, M., Jungius, H., Gamkrelidze, T., 2012. Ecoregion Conservation Plan for the Caucasus. 2012 revised and updated edition. Ga. Tbilisi WWF KfW BMZ.
Zürcher, C., 2007. The Post-Soviet Wars: Rebellion, Ethnic Conflict, and Nationhood in the Caucasus. NYU Press.