PUBLISHED BY
VOPROSY
EKONOMIKI
N. P.

Russian Journal of Economics 8 (2022) 276–294
DOI 10.32609/j.ruje.8.79738
Publication date: 6 October 2022

Russian
Journal of
Economics

www.rujec.org

Unexploded ordnance contamination and household livelihood choice in rural Vietnam

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Abstract

Vietnam is a country that found itself at the center of the Indochina wars and was subjected to the most intense aerial bombing in history. However, little research has been done on the effect of unexploded ordnance (UXO) contamination on household livelihoods in rural Vietnam. In this paper, we investigate the contaminating effect of unexploded ordnance on households. Livelihood choices are classified by cluster analysis techniques, and unexploded ordnance contamination is measured at the district level by the proportion of land at risk from unexploded bombs and mines. We examine the effect of UXO contamination on livelihood choices using a multinomial logit model, controlling for various important household and regional level characteristics. It was found that households in districts with greater contamination were less likely to adopt a formal wage-earning livelihood, characterized by higher income and less poverty, than they were to engage in an agricultural livelihood. This suggests that the Indochina wars have had a long-running effect, reducing the likelihood of non-farm diversification, which in turn diminishes economic well-being among rural households in Vietnam.

Keywords: contaminated land, unexploded ordnance contamination, rural livelihood, rural Vietnam, Vietnam War.
JEL classification: I32, N45, N55, Q12, Q15.

1. Introduction

In the course of the Indochina wars, Vietnam experienced three intense wars in the 20th century. The first commenced in 1945 and continued until the French were defeated in 1954, leading to the end of their rule in Indochina. In Vietnam, the second war is known as "the War against the Americans to Save

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the Nation" or, in the West, the "Vietnam War." This war began in 1955 between the government of North Vietnam (officially named the Democratic Republic of Vietnam — DRV) and the government of South Vietnam (the Republic of Vietnam) and its principal ally, the United States (U.S.) (Spector, 2021). This war ended in 1975, when the government of South Vietnam collapsed, ending thirty years of war, and the two parts of Vietnam were officially reunited in 1976. Following the war against the U.S., there was a third period of prolonged conflict. The Cambodian-Vietnamese war, known in Vietnam as the Counter-offensive on the Southwestern border, began in May 1975 and ended in December 1989, while the Sino-Vietnamese war broke out during the short period between February and March, 1979, on Vietnam's northern border (Spector, 2021).

These wars have left a terrible legacy in the form of agent orange/dioxin and unexploded ordnance contamination. From 1945–1975, more than 15 million tons of explosives were used in Vietnam, four times the amount deployed in World War II (Martin et al., 2019). During the conflict between Vietnam and the U.S. (1955–1975), the weight of bombs and other ordinance dropped by the United States Air Force was nearly triple that used in both the European and Pacific theaters in World War II, and about 15 times the total tonnage employed in the Korean War (Clodfelter, 1995). As a result, Vietnam has been severely contaminated by unexploded ordnance (UXO). UXO remnants have been found in most localities, in the plains, forests and mountainous areas, and under water. Official statistics from the Vietnam National Mine Action Centre (VNMAC, 2021) reveal that about 800,000 tons of uncleared UXO remain in all regions, contaminating, or possibly contaminating, about 6.1 million hectares and covering about 18.71% of the country's total area (Fig. 1).

For more than 40 years since the end of the wars in Vietnam, bombing intensity and UXO from various conflicts continue to have long-term negative effects on people's lives in the form of casualties (Martin et al., 2019) and adverse mental health effects (Phung et al., 2012; Singhal, 2019). To the best of our knowledge, however, little research has been done on the effects of UXO contamination on household livelihoods in rural Vietnam. A better understanding of these effects is necessary for academics and policy makers. This state of affairs inspired us to conduct the current study.

The main research objective of the current study is to identify the effect of UXO contamination on household livelihoods in rural Vietnam. Contamination is measured at the district level by the proportion of land with unexploded bombs and mines, while household livelihoods are classified using cluster analysis techniques. We examine the effect of UXO contamination on livelihood choices using a multinomial logit model, controlling for various important characteristics at the household and regional levels.

Our study broadens the scope of understanding by considering for the first time the effect of UXO contamination on household livelihood choice. In contrast with previous studies, which have investigated the effects of intensive bombardment during the Vietnam War on local socio-economic development or the consequences of childhood exposure to conflict on people's mental health in adulthood, our research examines the impact of UXO contamination. In addition, unlike in previous studies that focus only on provinces bombed during the Vietnam War, our research sample covers all 63 provinces that experienced all three wars, from

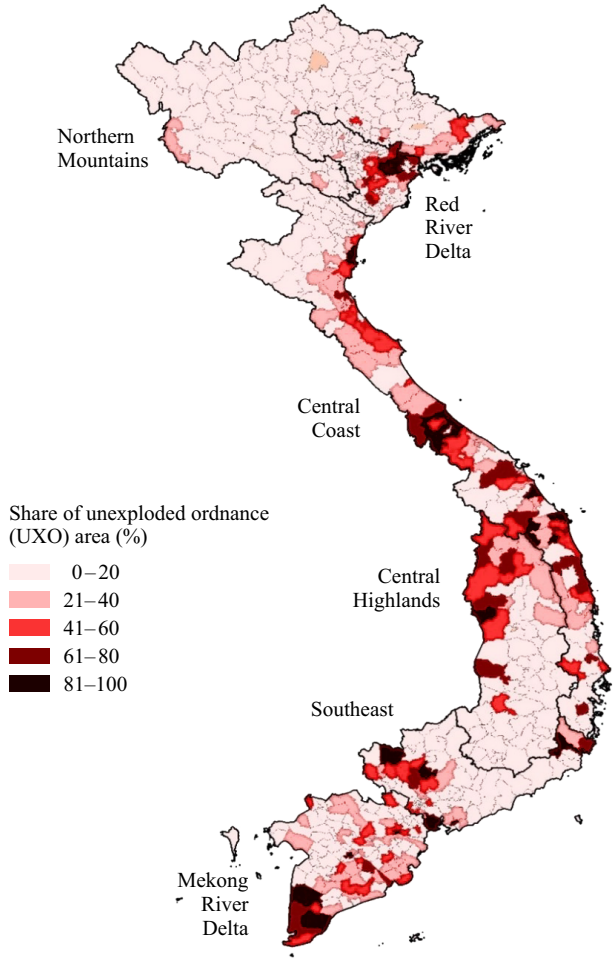

Fig. 1. Unexploded ordnance map of Vietnam's mainland.

Source: Authors' calculation using data from VNMAC (2021).

1945–1989. The rationale for this is that all 63 provinces and their cities are contaminated with UXO to various degrees (VNMAC, 2021).

Our micro econometric analysis shows that even after controlling for various household and commune-level factors, households in districts with greater contamination are less likely, on average, to adopt a formal wage-earning or non-laboring livelihood, which afford higher income, or at least a lower level of poverty than an agricultural livelihood. The finding suggests that the wars have had an adverse long-term effect on livelihood choices in rural Vietnam. Our study contributes to the scant extant literature on the long-term effect of war on the pursuit of household livelihoods in war-torn countries. Among the most terrible legacies of war, UXOs have resulted in adverse consequences for people's livelihoods.

The paper is structured as follows. The theoretical framework is given in Section 2, followed by the literature review in Section 3. Data and analytical methods are discussed in Section 4. Section 5 presents the empirical results and discussion, while Section 6 concludes with some policy implications.

2. Theoretical framework

Our study employs the rural sustainable livelihood framework proposed by Chambers and Conway (1992), Ellis (2000), and the Department for International Development (DFID, 1999a, 1999b). The term "livelihood" is defined in multiple ways. For example, Chambers and Conway (1992, p. 6) assert that "a livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living," adding that a "livelihood in its simplest sense is a means of gaining a living" (Chambers and Conway, 1992, p. 5).

Following Ellis (2000), our study defines a household livelihood choice as a combination of economic activities that create the means of household survival. Also, livelihood outcomes are measured by income and poverty at the household level. Last but not least, our study focuses on the condition of vulnerability that affects rural household livelihoods. Vulnerability is caused by several factors, such as wars and armed conflicts, natural hazards, economic shocks, and disease (DFID, 1999b). Specifically, our study investigates the contaminating effect of unexploded ordnance on livelihood choices among Vietnamese rural households.

Fig. 2 shows the analytical framework adjusted to the context of the current study, in which we focus on factors affecting livelihood choices. As shown in Fig. 2, household livelihood choices are determined by the availability of five

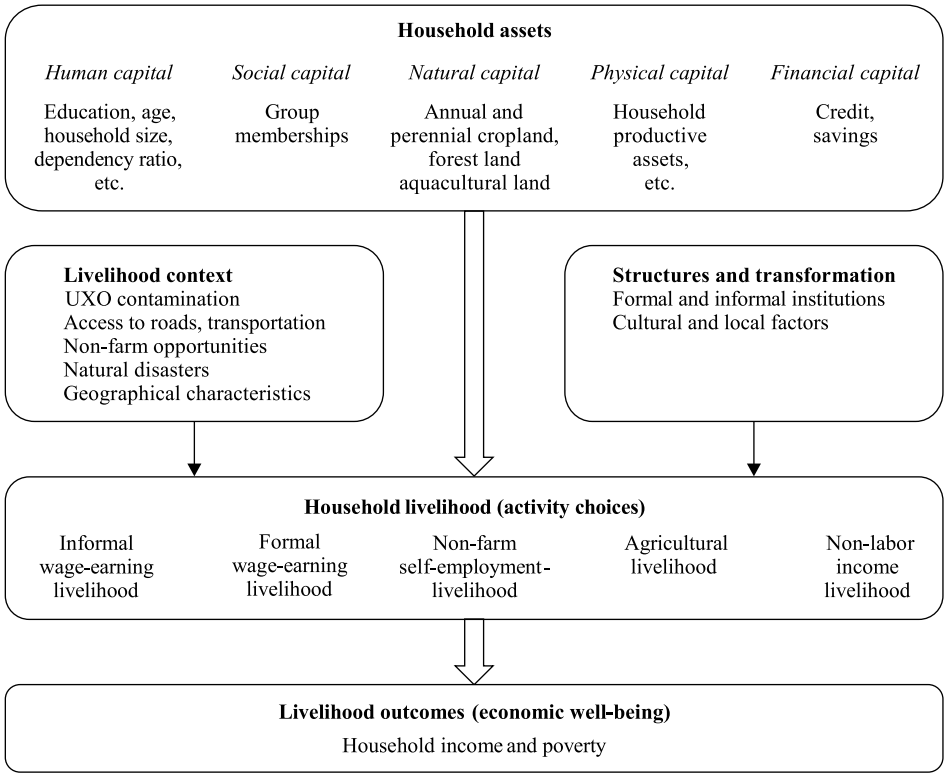

Fig. 2. Analytical framework for analyzing the impact of unexploded ordnance intensity on livelihood choice.

Source: Adapted from Babulo et al. (2008), DFID (1999) and Tran et al. (2014).

types of livelihood capital. Nevertheless, other exogenous factors, such as UXO contamination or access to public infrastructure, may have a direct impact on livelihood choice. Accordingly, such contextual livelihood factors must be taken into account in modeling the choice of household livelihood.

Our analytical paradigm also considers that stable or slowly varying assets, such as human, natural, and contextual elements, influence current household livelihood choices. Such variables are likely to be predetermined factors, since they are relatively stable through time (Van den Berg, 2010). Physical, financial, and social assets are not included as drivers of present livelihood choices since they are likely to be jointly determined with livelihood choices, or even determined by them (Jansen et al., 2006; Tran et al., 2014). The potential endogeneity problem will be minimized by omitting such capital assets from the model of livelihood choice (Jansen et al., 2006). Thus, only human, natural and contextual variables are included as determinants of livelihood choice in our analytical framework.

3. Literature review

Wars have terrible consequences for people's lives and their socio-economic development. They result in injuries and fatalities, they force displacement, destroy resources and infrastructure, damage the environment, undermine the social fabric, weaken civil liberties, and cause health crises and famine. Any of these factors or their combined effects have consequences for economic growth and development (Miguel and Roland, 2011). As noted by Azariadis and Drazen (1990), wars can cause "poverty traps." This poverty trap model was developed by the World Bank (2003), which pointed out that devastating wars destroy capital stock, leading to a "conflict trap" that pushes countries into long-term underdevelopment. Consequently, wars and armed conflicts constitute a major obstacle in the development process (Drèze, 2000; Singhal, 2019).

A systematic mixed studies review by Frost et al. (2017) reveals that in most of the countries affected, the unexploded detritus of war continues to have various negative consequences on people's lives, health, education, and economic activities. For instance, land mines or UXO have resulted in casualties, population displacement, increased health costs and food insecurity in Afghanistan, Bosnia, Cambodia, and Mozambique (Andersson et al., 1995), caused fatalities or inflicted psychological injuries in Iran (Asadoliahi et al., 2010) and Sri Lanka (Gunaratnam et al., 2003), caused a sharp rise in educational costs in Cambodia (Merrouche, 2011), and poverty in Mozambique (Merrouche, 2008). In Lebanon, the 2006 war led not only to the direct cost of damage to the infrastructure, but also generated indirect costs from the loss of opportunity to cultivate fields because of landmine contamination (Darwish et al., 2009). Landmines have also resulted in long-term negative effects on human capital. Examples include Angola, where landmines have had a causal effect on children's reduced height and weight for age (Arcand et al., 2015), while landmine contamination caused a 0.5–1-year decline in child educational attainment in Cambodia (Merrouche, 2011). Households that included a mine victim were 40% more likely to have difficulty in providing food for themselves in Afghanistan, Bosnia, Cambodia, and Mozambique (Andersson et al., 1995).

Despite their destructive short-term effects, some argue that wars are conducive to long-term development (Drèze, 2000) or at least have no adverse long-term effects (Miguel and Roland, 2011). Several reasons have been put forward for this connection, particularly the historical role of wars in state formation, nation building, and technological development (Drèze, 2000). It is often reported that military research and development may foster technological progress, and this may compensate for the negative consequences of wars (Miguel and Roland, 2011). Moreover, Miguel and Roland (2011) mention that wars may have served to promote state and national development in Europe (Tilly, 1975) and may stimulate social progress by encouraging more popular participation (Keyssar, 2000) or by removing the power of entrenched groups that constrain pro-growth policies (Olson, 2008). However, a recent study by Guo (2020) reveals the negative long-term effect of wars in Laos and, as a terrible legacy of the Vietnam War, the fact that the existence of UXO (at the village level) has significantly reduced farming efficiency and levels of education for individuals.

In Vietnam, a number of studies have examined the effect of U.S. bombing on local economic development (Miguel and Roland, 2011), people's mental health and educational attainment (Singhal, 2019), and early life shock and entrepreneurship (Churchill et al., 2021). Palmer et al. (2019) found that 40 years after the end of the Vietnam War, exposure to the results of bombardment increased disability rates at the district level. Singhal (2019) provides evidence that at the individual level also, early life exposure to intense bombing from 1965–1975 increased the risk of suffering from severe mental problems.

However, these long-term effects were not found or even appeared to be positive in some studies. For example, Miguel and Roland (2011) were unable to identify a causal relationship between intense bombing and district level effects on poverty and consumption, infrastructure, literacy, and population density. Notably, a study by Churchill et al. (2021) reveals that individuals who suffered from early life shock from intense bombing were more likely to be self-employed. The authors explain that exposure to adverse childhood events may teach individuals to be more self-reliant (Bonanno, 2004), resilient (Bullough et al., 2014), and more willing to take risks (Haushofer and Fehr, 2014), all of which are major characteristics of entrepreneurs (Ayala and Manzano, 2014; Cope, 2011).

While there is a close link between bombing intensity and UXO contamination (Miguel and Roland, 2011), the literature concerning Vietnam and other countries shows that there is no econometric evidence for the subsequent impact of UXO intensity on people's livelihood choices. Given the importance of the research topic and the gap in the literature, it is essential to investigate the impact of UXO contamination on household livelihood options in rural Vietnam.

4. Data and econometric model

4.1. Data and research indicators

First, UXO contamination is measured by the proportion of land with UXO remnants at the district level, using data from VNMAC (2021), taken from a survey lasting three years (from 2010–2013) in all 63 provinces. It should be noted that UXO data were only collected in this survey, and UXO issues remained

almost unchanged between 2013 and 2018. This is because the nation's UXO issue has only been addressed since March 2018, when the Vietnamese Ministry of National Defense established the Office of the Standing Agency of the National Steering Committee for the Settlement of Post-war Unexploded Ordnance and Toxic Chemical Consequences (Martin et al., 2019).

Second, we also utilize recent data from the Vietnam Household Living Standard Survey in 2018 conducted by the General Statistical Office of Vietnam. This allows us to get up-to-date information about rural households' characteristics and figure out which livelihood strategy they choose. This survey collected detailed information about various socio-economic characteristics of households and the communes where they live. Household-related characteristics include demography, education, occupation and economic activities, land ownership, and assets, while commune-related characteristics consist of population, land, infrastructure, and regional geography. The data from the two sources are merged to create a unique dataset which includes details concerning the UXO contamination district as well as household/commune-level data.

We adopt the cluster analysis technique to identify which livelihood strategies are currently chosen by rural households. This technique allows researchers to group similar households into a number of clusters based on the observed values of several variables for each household (Everitt et al., 2011). This method is commonly applied in various fields such as medicine, psychology, marketing, and economics (Everitt et al., 2011). Following Ellis (2000) and empirical studies in Vietnam (Hoang et al., 2019, 2020), we use the various proportions of income sources as input variables for cluster analysis. Because the selected household sample includes rural households, five income sources are used, namely: (i) informal wage income (income from wage-paying work without a formal labor contract); (ii) formal wage income (income from wage-paying work with a formal labor contract); (iii) non-farm income (income from non-farm self-employment activities at the individual or household level); (iv) agricultural income (income from cultivation, fisheries, livestock and forestry) and (v) non-labor income or other sources of income (income from remittances, transfers, rentals and interest, etc.).

We employ the two-stage cluster analysis approach recommended by Punj and Stewart (1983). First, the preliminary identification of clusters is implemented via the average linkage method. Specifically, from the pairwise distance matrix we employed the Calinski—Harabasz pseudo-F for stopping rules in cluster analysis, commonly used to identify the optimal number of clusters (Halpin, 2016). The results showed that the largest value of pseudo-F was 7055.54, corresponding to five clusters (see Appendix Table A1). Second, we use the K-mean cluster to classify households according to mutually exclusive livelihoods. Finally, we labeled, defined, and interpreted the clusters by comparing income structure across livelihoods.

4.2. Econometric model

Because the dependent or response variable has five categories, we use a multinomial logit model (MNL) to investigate factors associated with household livelihood choice (Train, 2003). The MNL model is the most widely used for nominal outcomes because of its fast calculation and straightforward interpreta-

tion (Cheng and Long, 2007). Equation (1) was used to identify factors associated with livelihood choice among rural households:

$$P_{ij}(j = k|X_i) = \beta_0 + \beta_1 X_{ij} + \beta_2 Z_{ij} + \beta_3 R_j + \varepsilon_{ij}, \quad (1)$$

where β_i is the parameter that needs to be estimated; X_{ij} is a vector of household characteristics; Z_{ij} represents UXO contamination; R_j is the region-related variable and ε_{ij} is an error term.

In equation (1), UXO contamination Z_{ij} is the variable of interest. As discussed in the framework and literature, UXO remnants may explode and kill or disable many people if touched, stepped on, disturbed, and may even explode spontaneously. Also, large infrastructure and industrial projects are needed to organize costly clearance operations (Landmine and Cluster Munition Monitor, 2007; Tuoitre, 2019).[1] Both risk and cost discourage individuals and firms from investing in or expanding their economic activities in localities with contaminated land. Consequently, it is hypothesized that UXO intensity undermines the probability of adopting a profitable livelihood choice for local people.

Another possible source of concern is that UXO density tends to be higher in provinces closer to the 17th latitude and those in the west of South Vietnam, those in coastal areas and some parts of Hanoi (see Fig. 1). Accordingly, we control for province fixed effects in the model because the variation in UXO density within a province is considered to be more exogenous (Nguyen et al., 2022). Also, we control for various district and commune-level variables which can affect household livelihoods. The inclusion of regional dummy variables captures differences in inter-region fertility of farmland, development of infrastructure, cultural, historical and institutional province level factors that may affect household livelihood strategies.

Following the analytical framework and literature review in Section 2, we include several variables in the model, as defined and measured in Table 3. Household-related variables include the age, education, gender and ethnicity of household heads, various types of land owned, household size and dependency ratio. Commune-level variables consist of the number of people per hectare, the proportion of agricultural, aquacultural and forest lands, access to roads and transportation, natural disasters, non-farm opportunities, and geographic regions. Our regression analysis accounts for sampling weights and is clustered at the village level.

5. Results and discussion

5.1. Descriptive statistics analysis

This section analyzes the main characteristics of households by livelihood. Table 1 shows that on average, agricultural income contributes about 28% of total income for the whole sample, followed by informal wage income (22%),

[1] For example, a recent event shows that more than 1,700 people were evacuated from their houses on April 25, 2021 as the provincial authorities of Vinh Phuc defused an unexploded 340 kg bomb dropped by the U.S. Air Force during the Vietnam War (Phuong, 2021).

Table 1
Mean share of income sources by livelihood (%).

Livelihood	Income source by livelihood						
	Formal wages	Informal wages	Agricultural income	Non-farm income	Other income	Number of observations	Percent
Non-labor income	3	4	13	3	77	3,758	14
Informal wage-earning	4	69	15	3	9	6,817	25
Formal wage-earning	72	7	9	4	7	5,741	21
Agricultural	3	8	75	3	11	6,840	25
Non-farm income	5	5	9	73	8	4,030	15
Whole sample	18	22	28	14	18	27,186	100

Source: Authors' calculations using data from General Statistics Office (2019).

formal wage income (18%) and other income (18%), while non-farm income accounted for only 14%. The data in the final column of Table 1 show that a quarter of total households pursued an agricultural livelihood, and the same number was also found for those with an informal wage-earning livelihood. About 21% of households adopt a livelihood based on formal wage-earning work, while only 15% and 14% depend on a non-farm livelihood and non-labor livelihood, respectively.

Table 1 also describes the mean income percentage by source across livelihoods. On average, the mean percentage of other income accounts for about 77% of the household total for those with a non-labor income livelihood. On average, those with an informal wage-earning livelihood earned about 70% of their total income from informal wage-paying work. Of total income, 72% came from formal wage-earning work for those with a formal wage-paying livelihood. The mean proportion of agricultural income contributes about 75% of total income for those specializing in agriculture, while those adopting a non-farm livelihood earned on average about 73% of their total income from non-farm activities.

Table 2 compares household economic well-being across livelihoods. For the whole sample, the mean and median income per capita is about 3.02 and 2.47 million VND per month, respectively. The mean income is highest for households pursuing a non-farm livelihood (about 4 million VND), followed by those with a formal wage-paying livelihood (3.65 million VND). The lowest mean income is observed for those in the informal wage-earning livelihood group (about 2.4 million VND). Comparing median income across livelihoods reveals that the same levels of income as well as the highest are found for those with formal wage-paying and non-farm livelihoods. Also, those adopting an informal wage-earning livelihood had a higher median income level than those pursuing an agricultural livelihood. Overall, the data suggests that formal wage and non-farm livelihoods are more profitable than others.

Descriptive statistics analysis in Table 2 shows that the poverty rate is about 6.5% for the whole sample. Households following an agricultural livelihood tend to be the poorest ones, with a poverty incidence of about 15.40%. The poverty rate is also quite high for those with a non-labor livelihood (about 9.20%) while the lowest is found for those with a formal wage-paying (0.37%) or non-farm livelihood (0.99%). Surprisingly, while those adopting informal wage-earning

Table 2
Household economic well-being by livelihood type.

Livelihoods		Income per person, million VND	Poverty incidence, %
Non-labor income livelihood	Mean	2.744	9.18
	Median	1.852	
	SD	3.081	
Informal wage-earning livelihood	Mean	2.434	4.53
	Median	2.149	
	SD	1.469	
Formal wage-earning livelihood	Mean	3.659	0.37
	Median	3.298	
	SD	1.856	
Agriculture livelihood	Mean	2.613	15.39
	Median	1.759	
	SD	3.853	
Non-farm income livelihood	Mean	4.051	0.99
	Median	3.276	
	SD	3.587	
Total	Mean	3.020	6.50
	Median	2.474	
	SD	2.933	

Note: Poverty incidence was calculated using the General Statistics Office (2019, Section 9) poverty line.
Source: Authors' calculations using data from General Statistics Office (2019).

livelihoods had mean and median income levels no higher than those in the agricultural livelihood group, the former had a much lower poverty rate than did the latter (4.53% vs 15.40%).

Statistical inferential analysis was performed to draw conclusions about the population from the household sample. Specifically, we compare income levels across livelihoods using a Bonferroni multiple comparison test (see the results in Appendix Table A2). This analysis confirms that monthly average income per capita is highest for households with a non-farm livelihood, followed by those with a formal wage-earning livelihood, a non-labor livelihood, an agricultural livelihood, and an informal wage-paying livelihood. Finally, we test the difference in poverty incidence across livelihoods using Dunn's pairwise comparison with Bonferroni adjustment (see the results in Appendix Table A3). The test shows that the highest poverty incidence is observed for households in the agricultural livelihood group, then for those depending on a non-labor income livelihood, while the third group are those with an informal wage-earning livelihood. As already discussed, the poverty incidence is lowest for those with a formal wage-paying or non-farm livelihood, while there is no statistically significant difference in the poverty rate between these two groups.

The main characteristics of households are given in Table 3. The data shows that the proportion of household heads belonging to the ethnic majority (Kinh/Hoa) group is much lower for those in the agricultural livelihood group than in other livelihood groups. Specifically, 60% of household heads are Kinh/Hoa people for households with an agricultural livelihood while the corresponding figures are about 93% for those with a non-farm livelihood, or 76% for those with an

Table 3
Summary of included variables by livelihood.

Household/commune/district characteristics	Livelihood group											
	Non-labor income		Informal wages		Formal wages		Agriculture		Non-farm		Whole sample	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ethnicity (1 = Kinh/Hoa; 0 = minorities)	0.88	0.32	0.76	0.43	0.89	0.31	0.63	0.48	0.93	0.26	0.80	0.40
Gender (1 = male; 0 = female)	0.59	0.49	0.79	0.41	0.76	0.43	0.86	0.35	0.80	0.40	0.78	0.42
Age (years)	63.87	14.76	48.81	12.11	52.38	13.55	50.80	12.67	49.83	11.72	52.30	13.76
Marital status (1 = married;0 = single)	0.59	0.49	0.81	0.39	0.83	0.38	0.87	0.34	0.85	0.35	0.81	0.40
Formal years of schooling	5.96	3.95	6.49	3.67	9.67	4.09	6.36	3.71	8.35	3.62	7.33	4.06
Household size (family members)	2.41	1.38	3.89	1.49	3.99	1.53	3.90	1.67	3.92	1.51	3.71	1.62
Dependency ratio	0.66	0.38	0.32	0.25	0.38	0.29	0.36	0.29	0.35	0.27	0.39	0.31
Annual cropland (square meters)	1,837	5,092	1,940	3,333	1,740	3,929	7,132	35,000	1,746	5,744	3,161	18,111
Perennial cropland (square meters)	637	3,109	671	2,481	763	3,921	4,130	14,802	1,025	10,670	1,609	8,959
Forest land (square meters)	1,001	10,345	1,634	8,867	834	5,124	4,678	34,948	1,138	8,115	2,070	18,959
Horticultural land (square meters)	159	729	152	593	160	549	358	1518	121	618	202	933
Population per hectare at commune level	737	889	666	1,196	879	1,369	387	675	894	1,497	685	1,161
UXO contamination (district proportion of land with UXO)	0.31	0.30	0.28	0.29	0.30	0.31	0.24	0.29	0.31	0.31	0.28	0.30
Proportion of agricultural land at the commune level	0.56	0.25	0.52	0.26	0.55	0.23	0.49	0.30	0.56	0.24	0.53	0.26
Proportion of aquacultural land at the commune level	0.05	0.12	0.05	0.12	0.05	0.09	0.05	0.16	0.06	0.13	0.05	0.13
Proportion of forest land at the commune level	0.15	0.25	0.21	0.28	0.14	0.23	0.28	0.31	0.14	0.23	0.19	0.27
Access to roads (1 = yes; 0 = no)	0.96	0.20	0.97	0.18	0.98	0.13	0.91	0.28	0.98	0.15	0.96	0.20
Transportation (1 = yes; 0 = no)	0.49	0.50	0.48	0.50	0.48	0.50	0.43	0.50	0.54	0.50	0.48	0.50
Non-farm opportunities (1 = yes; 0 = no)	0.80	0.40	0.78	0.42	0.84	0.36	0.64	0.48	0.85	0.36	0.77	0.42
Natural hazards (number of times during the last 12 months)	1.13	1.41	1.24	1.55	0.99	1.66	1.36	1.74	1.02	1.32	1.17	1.58
Coastal area (1 = yes; 0 = no)	0.07	0.26	0.06	0.24	0.03	0.18	0.05	0.22	0.05	0.22	0.05	0.22
Inland area (1 = yes; 0 = no)	0.64	0.48	0.52	0.50	0.63	0.48	0.38	0.49	0.65	0.48	0.54	0.50
Midlands (1 = yes; 0 = no)	0.03	0.16	0.03	0.18	0.05	0.22	0.02	0.14	0.04	0.19	0.03	0.18
Low mountainous area (1 = yes; 0 = no)	0.17	0.38	0.22	0.42	0.19	0.40	0.18	0.38	0.18	0.38	0.19	0.39
High mountainous area (1 = yes; 0 = no)	0.09	0.29	0.17	0.37	0.09	0.29	0.37	0.48	0.09	0.28	0.18	0.39
Observations	3,758		6,817		5,741		6,840		4,030		27,186	

Source: Authors' calculations using data from General Statistics Office (2019).

informal wage-earning livelihood. Moreover, a higher percentage of male-headed households is observed for those in agricultural livelihoods than in other livelihood groups. The average age of the household head is higher for those with a non-labor income livelihood, possibly because older people tend to rely on non-labor income sources for their living.

With respect to the number of years of formal schooling of household heads, the data in Table 3 reveals that the highest level is found for those with a formal wage-earning livelihood (9.67 years); the second level — for those with a non-farm livelihood (8.35 years); while the lowest level is recorded for those in the non-labor income livelihood group (5.96 years). The education level of household heads in informal wage-earning and agricultural livelihoods is 6.49 and 6.36 years, respectively. The data here suggest that a higher education level is closely linked to profitable livelihoods. Also, household heads with a non-labor income livelihood are older, on average, than those in other livelihoods and also have a much smaller household size and greater dependency ratio than those adopting other livelihoods. Unsurprisingly, those following an agricultural livelihood owned much more land than those who pursued other livelihoods. For instance, the mean size of annual cropland is about 7,132 square meters for households in the agricultural livelihood group, while the corresponding figure is about 1,740 square meters for those with a non-farm livelihood or who depend on formal wages. Similar trends are also found for other types of land.

Table 3 demonstrates that, on average, about 28% of each district's total land is contaminated with UXO in rural areas, which is much higher than that of the whole country (18.71%) as shown in Fig. 1. An examination of the livelihood of each group reveals that households with an agricultural livelihood tend to live in districts with lower levels of contamination. The proportion of contaminated land for this livelihood group is about 24%, compared to about 28–31% in other livelihood groups. Also, households engaged in an agricultural livelihood tend to reside in communes with more land per capita and a larger proportion of forest land, while they are less likely to have access to roads, transportation and non-farm opportunities. Finally, as to location, these households are widely distributed in high mountainous areas compared to those with other livelihoods. The findings imply that some regional characteristics are associated with household livelihood choice.

5.2. Econometric results

Table 4 demonstrates the regression results for factors associated with livelihood choice. We report the results in terms of coefficients and interpret with relative risk ratios (RRR), which are the exponentials of the coefficients. The RRR is one probability divided by another. In our study, this is the probability of a household choosing a given livelihood (e.g., a formal wage-earning livelihood) divided by the probability of the household pursuing an agricultural livelihood. The results show that many explanatory variables are statistically highly significant, and the value of pseudo R-squared is 0.2, suggesting that the model has good explanatory power (Louviere et al., 2000).

The coefficient of UXO contamination is negative and statistically highly significant for the pursuit of formal wage-earning or non-labor livelihoods.

Table 4
The impact of unexploded ordnance (UXO) contamination on livelihood choice.

Household/commune/district characteristics	Livelihood group vs agriculture							
	Non-labor income		Informal wages		Formal wages		Non-farm	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Ethnicity (1 = Kinh/Hoa; 0 = minorities)	–0.30***	(0.113)	–0.49***	(0.122)	–0.12	(0.105)	0.74***	(0.130)
Gender (1 = male; 0 = female)	–0.78***	(0.116)	–0.29***	(0.081)	–0.88***	(0.076)	–0.54***	(0.100)
Age (years)	0.03***	(0.002)	–0.02***	(0.002)	0.02***	(0.003)	–0.01***	(0.002)
Marital status (1 = married; 0 = single)	0.28**	(0.132)	–0.17*	(0.094)	0.11	(0.111)	0.16	(0.133)
Formal years of schooling	0.02**	(0.010)	–0.02**	(0.008)	0.22***	(0.010)	0.12***	(0.007)
Household size (family members)	–0.32***	(0.034)	0.18***	(0.016)	0.32***	(0.019)	0.28***	(0.022)
Dependency ratio	1.47***	(0.077)	–0.71***	(0.077)	–0.59***	(0.098)	–0.53***	(0.082)
Annual cropland (square meters)	–0.30***	(0.028)	–0.41***	(0.021)	–0.48***	(0.033)	–0.54***	(0.035)
Perennial cropland (square meters)	–0.38***	(0.030)	–0.47***	(0.024)	–0.49***	(0.031)	–0.53***	(0.029)
Forest land (square meters)	–0.11***	(0.026)	–0.14***	(0.029)	–0.16***	(0.029)	–0.10***	(0.028)
Horticultural land (square meters)	–0.25***	(0.054)	–0.23***	(0.038)	–0.21***	(0.044)	–0.41***	(0.048)
Population per hectare at the commune level	0.04	(0.094)	0.20***	(0.060)	0.25***	(0.077)	0.36***	(0.063)
UXO contamination at the district level	–0.51**	(0.209)	–0.06	(0.194)	–0.45***	(0.166)	–0.16	(0.184)
Proportion of agricultural land at the commune level	–0.60	(0.446)	–0.12	(0.270)	–0.35	(0.326)	–0.08	(0.310)
Proportion of aquacultural land at the commune level	–1.73***	(0.588)	–1.43***	(0.479)	–1.93***	(0.426)	–1.55***	(0.501)
Proportion of forest land at the commune level	–0.33	(0.488)	–0.01	(0.304)	–0.33	(0.384)	0.17	(0.320)
Access to roads (1 = yes; 0 = no)	0.30*	(0.169)	0.68***	(0.123)	0.80***	(0.284)	0.98***	(0.230)
Transportation (1 = yes; 0 = no)	0.09*	(0.051)	0.14***	(0.050)	0.06	(0.064)	0.18**	(0.081)
Non-farm opportunities (1 = yes; 0 = no)	–0.17	(0.108)	0.10	(0.076)	0.02	(0.119)	0.13	(0.120)
Natural hazards (number of times during the last 12 months)	–0.01	(0.032)	0.02	(0.021)	0.01	(0.030)	–0.02	(0.029)
Inland areas (1 = yes; 0 = no)	0.44**	(0.177)	0.73***	(0.178)	0.91***	(0.287)	1.12***	(0.190)
Midlands (1 = yes; 0 = no)	0.50**	(0.238)	0.76***	(0.263)	1.07**	(0.427)	1.08***	(0.331)
Low mountainous areas (1 = yes; 0 = no)	0.33	(0.226)	0.98***	(0.171)	0.91***	(0.291)	1.40***	(0.160)
High mountainous areas (1 = yes; 0 = no)	0.00	(0.307)	0.66***	(0.182)	0.58*	(0.313)	0.90***	(0.232)
Provincial dummies (included)								
Constant	–0.08	(0.670)	1.11**	(0.481)	–3.70***	(0.807)	–3.98***	(0.613)
Pseudo R^2	0.20							
Observations	27,141		27,141		27,141		27,141	

Note: Estimates account for sampling weights and are clustered at the commune level; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations using data from General Statistics Office (2019).

Robust to the choice of various important control variables, our research finding indicates that contamination has a negative effect on choosing these livelihoods relative to the choice of an agricultural livelihood (the reference group). Specifically, given a 10 p.p. increase in the area of contaminated land, the relative probability of choosing a formal wage-earning livelihood would decline by –4.4%, holding all other factors in the model constant. The corresponding effect for the choice of a non-labor livelihood is –4.97%. The effect is quite small, however, and not statistically significant (p-value > 0.10) for other livelihood choices, such as the informal wage-earning or non-farm livelihood groups.

The negative effect can be explained by the fact that unexploded remnants of war are costly for organizations and individuals to find and remove (Tuoitre, 2019), hindering the use of contaminated land (Landmine and Cluster Munition Monitor, 2007). Clearly, this situation is likely to be an obstacle for expanding local economic activity, particularly for large-scale firms or foreign direct investment (FDI) firms, and in turn may diminish the likelihood of rural people engaging in formal wage-paying employment in factories or big companies. This argument is notably supported by a recent study by Nguyen et al. (2021), who provide robust econometric evidence of the negative long-term impact of UXOs on the density of FDI and large-scale firms across districts of Vietnam. Because rural households with formal wage-earning or non-labor livelihoods have higher income on average, or at least a lower poverty level, than do those specializing in agriculture, our finding suggests that the wars have had a long-term adverse effect on household livelihood choice in rural Vietnam. The finding is partly consistent with that of Merrouche (2008) for Mozambique, where UXO contamination was found to increase poverty and lower consumption at the district level, even many years after the ceasefire. Similarly, the intensity of UXO was found to reduce farming efficiency and education levels for individuals in Laos (Guo, 2020).

We also find several other factors associated with livelihood choice in rural Vietnam. Households headed by members of the Kinh/Hoa group are more likely to pursue a non-farm livelihood but are less likely to adopt an informal wage-earning livelihood or a non-labor livelihood. The coefficient of the gender variable is negative and statistically significant for all livelihood choices, indicating that households headed by men have a higher relative probability of choosing an agricultural livelihood. Larger household size reduces the relative likelihood of households pursuing a non-labor livelihood but increases that of taking up other livelihoods (e.g., wage-earning or non-farm livelihoods). Also, households with a higher dependency ratio are more likely to adopt a non-labor livelihood but less likely to undertake wage-earning or non-farm livelihoods. The finding implies that households with more members tend to have less land per capita, which in turn induces them to diversify out of agriculture. Similar findings are found in Cambodia (Do et al., 2019) and rural Africa (Nagler et al., 2014).

As with previous findings in most developing countries (Rigg, 2006; Tran, 2014), we find that better education enables households to pursue more profitable livelihoods. Specifically, an additional year of formal schooling increases the relative probability of choosing a formal wage-earning livelihood by 24.6% and a non-farm livelihood by 12.75%, holding all other factors constant in the model. As

expected, households with more cropland or forest land are more likely to pursue an agricultural livelihood.

The study finds that livelihood choice is also influenced by certain commune characteristics. Living in a populous commune increases the likelihood of households pursuing various wage-earning or non-farm livelihoods. Also, the probability of choosing such livelihoods is closely linked with access to roads and transportation. Finally, households in coastal communes are less likely to take up non-farm or wage-earning livelihoods than those in inland, midland, and mountainous communes.

6. Conclusion and policy implications

Numerous studies have confirmed the negative effects of explosive remnants of war on people's lives and health, including direct physical, psychological, and other social and economic effects. In Vietnam, the consequences of the intense bombing endured during the Vietnam War on local socio-economic development have been investigated at the district level. Similarly, the war's effect on people's mental health in adulthood from their exposure to war in early life has been examined. Our study broadens the scope of understanding by quantifying the effect of UXO contamination on household livelihood choice in rural Vietnam.

Robust to the choice of various important household and commune-related characteristics, our econometric analysis shows that UXO contamination has a negative effect on the choice of a profitable livelihood. Relative to an agricultural livelihood as the reference group, our economic results show that rural households in districts with greater contamination are less likely to adopt a formal wage-earning livelihood or non-labor source of income. As already discussed, a plausible explanation here is that contamination from war incurs enormous financial costs at a time of rapid economic development in Vietnam and requires major infrastructure and industrial projects to prepare for costly clearance operations (Landmine and Cluster Munition Monitor, 2007; Tuoitre, 2019). Consequently, this undertaking may hinder the establishment and expansion of local economic facilities, which, in turn, limits profitable livelihood opportunities for local households.

UXO fragments have been located in almost every area, in fields, woodlands, and mountainous areas, as well as under water. Despite continuous efforts by the Vietnamese government, the U.S., and other international contributors, the removal of Vietnam's UXO could take 100 years or more at the current rate (Martin et al., 2019). This suggests that extensive areas with UXO contamination will continue to be unavailable for agriculture, industry, or habitation, preventing economic development of localities. As a result, UXOs have a negative impact on agricultural production, as well as mining, forestry, hydropower development, and the construction of roads, schools, and clinics (Martin et al., 2019). However, since they have no other source of livelihood, farmers have to take the risk of continuing to cultivate contaminated land, even though they are aware of the danger (Nguyen, 2020). With a view to establishing sustainable rural livelihoods, our research finding implies that speeding up UXO clearance offers important synergistic gains, not only in reducing injury and fatality risks, but also in improving livelihood opportunities for affected communities.

Several other factors are also identified, affecting livelihood choice. Kinh/Hoa groups have greater opportunity to adopt a profitable livelihood than do ethnic minorities, while households with better education are more likely to obtain a better livelihood. The findings suggest that expanding livelihood opportunities for ethnic minorities and providing additional education for poorly educated people would enable them to secure better livelihoods. Finally, judging from the positive effects of access to roads and transportation, a useful policy implication here is that improving such access could be an effective way of creating favorable livelihood opportunities for local households.

We acknowledge that our study has certain limitations. While our econometric analysis shows a statistically significant association between UXOs and livelihood issues, the tools it employs may not be sufficient to establish a causal relationship between the two variables. The research's conclusions would be more convincing if supported by specific primary data on the link between unexploded ordnance and related issues on the ground. This limitation, therefore, suggests an interesting topic for future research.

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Appendix

Table A1
Cluster analysis results (first stage).

Number of clusters	Calinski/Harabasz pseudo-*F*
2	1297.54
3	2735.68
4	4287.95
5	7185.12
6	6390.75
7	5633.10
3	5417.67
9	6020.15
19	5621.89
11	6121.32
12	5975.97
13	5899.92
14	6064.78
15	6454.72

Source: Authors' calculations.

Table A2
Bonferroni multiple-comparison test of per capita income by livelihood.

Row mean	Column mean			
	1. Non-labor income	2. Informal wages	3. Formal wages	4. Agriculture
2. Informal wages	–488.31			
p-value	0.00			
3. Formal wages	741.96	1230.28		
p-value	0.00	0.00		
4. Agriculture	–282.30	206.01	–1024.27	
p-value	0.00	0.00	0.00	
5. Non-farm	1164.08	1652.39	422.12	1446.38
p-value	0.00	0.00	0.00	0.00

Note: Income measured in thousands of Vietnamese dong.
Source: Authors' calculations.

Table A3
Dunn's pairwise comparison of poverty incidence by livelihood, using Bonferroni adjustment.

Row mean	Column mean			
	1. Non-labor income	2. Informal wages	3. Formal wages	4. Agriculture
2. Informal wages	9.28			
p-value	0.00			
3. Formal wages	17.04	9.43		
p-value	0.00	0.00		
4. Agriculture	–12.40	–25.70	–34.10	
p-value	0.00	0.00	0.00	
5. Non-farm	14.64	7.23	–1.24	29.41
p-value	0.00	0.00	1.00	0.00

Note: Poverty incidence was calculated using the General Statistics Office (2019, Section 9) poverty line.
Source: Authors' calculations.