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ORIGINAL ARTICLE

Economic inequality expanded after an extreme climate event: a long-term analysis of herders' household data in Mongolia

Kaoru Kakinuma[1] · Kohei Tamura[2,7] · Hiroki Takikawa[3] · Yuichiro Fujioka[4] · Kazuhiro Kezuka[5] · Hiroshi Nakamura[6]

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Abstract

The importance of ending poverty and reducing economic inequality has been explicitly recognized globally. Climate extremes are a critical global risk and can lead to economic damages, but empirical evidence of their effects on economic inequality is limited. Here, we focus on Mongolian pastoralism, which has a coupled socio-ecological system, to examine the trend of economic inequality among herders following a climate extreme event. Mongolia experienced a winter disaster in 2009 that caused a mortality of about 20% of the total number of livestock across the country. We used a long-term livestock panel dataset at the household level ($n = 787$) during 2004–2013 to examine changes in the economic distribution after the disaster. Economic inequality increased after the disaster (Gini coefficient increased from 0.46 to 0.61), and the increased level of inequality remained 4 years after the disaster. A decomposition of the inequality analysis showed that within-group inequality largely contributed to the greater total inequality, and household groups with a small number of livestock had the largest increase in inequality. Moreover, household groups that did not recover their livestock number had a higher loss rate of livestock during the disaster than household groups that did recover. Although the number of total livestock in the study area did recover after 4 years, we empirically showed that inequality among herders increased after the disaster. This result suggests that economic distributions are critical when examining the socio-economic impacts of climate extremes. We also suggest that preparing for disasters during normal years to alleviate loss of livestock during a disaster, especially for households with a small number of livestock, is a critical way to reduce poverty in the face of more frequent climate extremes.

Keywords Economic impact · Extreme weather · Socio-ecological system · Winter disaster

Introduction

Climate extremes present significant global economic risks (Coronese et al. 2019; World Economic Forum 2021), and future climate change may amplify the impacts of climate extremes on social and economic conditions (IPCC 2022;

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✉ Kaoru Kakinuma
k.kakinuma0214@gmail.com

1 Center for Desert Agriculture, Biological and Environmental Sciences & Engineering Division (BESE), King Abdullah University of Science and Technology (KAUST), 23955-6900 Thuwal, Saudi Arabia

2 Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Aoba-6-3 Aramaki, Aoba Ward, Sendai, Miyagi 980-0845, Japan

3 Graduate School of Humanities and Sociology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8654, Japan

4 Graduate School of Integrated Scineces for Global Society, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

5 Department of Empirical Social Security Research, National Institute of Population and Social Security Research, 2-2-3 Uchisaiwaicyo, Chiyoda-ku, Tokyo 100-0011, Japan

6 Sanyo-Onoda City University, Daigakudori 1-1-1, Sanyo-Onoda, Yamaguchi 756-0884, Japan

7 Center for Northeast Asian Studies, Tohoku University, 41 Kawauchi, Aoba Ward, Sendai, Miyagi 980-8576, Japan

Mora et al. 2018). At the same time, eradicating extreme poverty and reducing economic inequalities by 2030 (United Nations Sustainable Development Goals [SDGs] 1 and 10) are also critical global issues. We need to reduce poverty while also facing a changing climate.

Poverty makes people or societies vulnerable to the effects of climate change at various levels, from households (Jardine et al. 2020; Nakamura et al. 2017; Keerthiratne and Tol 2018) to countries (Mendelsohn et al. 2006; Ahmed et al. 2009; Diffenbaugh and Marshall 2019; Baarsch et al. 2020). For example, the economic loss from a heat wave was more severe for small vessels than it was for large vessels in California fisheries (Jardine et al. 2020). Poor households, which have higher shares of incomes from agriculture, were more affected by natural disasters between 1990 and 2013 in Sri Lanka (Keerthiratne and Tol 2018). While vulnerabilities to climate extremes at the household level have been discussed, few studies have focused on economic structural changes (i.e., economic inequality) within a country, including the damage and recovery processes after climate extremes, due to data limitations. Long-term panel datasets are required to assess the impact of extreme climate events on economic distribution changes (Angelsen and Dokken 2018). Moreover, it is difficult to extract the effects of extreme climate events on economic inequality because of the complex interactions between social and environmental factors (Hamann et al. 2018; Millward-Hopkins and Oswald 2021). A simple relationship between society and the natural environment is necessary to examine the trend of economic inequality after an extreme climate event. These reasons may result in limited empirical evidence on how climate extremes change economic inequality within a country (Angelsen and Dokken 2018; Hallegatte and Rozenberg 2017; Palagi et al. 2022).

Mongolia has a coupled socio-ecological system (Kakinuma et al. 2019; Lee et al. 2015). Its history of pastoralism has spanned over millennia (Baroni et al. 2016; Honeychurch 2015), and 26.6% of all households were engaged in herding in 2020 (Mongolia Statistical Information Service 2021). Herders' livelihoods largely rely on climate and dryland ecosystem conditions (Kakinuma et al. 2019; Lee et al. 2015), and future climate change could have severe consequences for people in these environments (Birkmann et al. 2023, in press). In addition, the climate in Mongolia has been getting hotter and drier since the 1960s, and it is critically important to examine the impacts of climate extremes on this type of pastoral society (Haraguchi et al. 2022; Kakinuma et al. 2019; Nandintsetseg et al. 2021). Severe winter disasters (known as a '*dzud*' in Mongolian) often hit livestock in Mongolia (Sternberg 2010; Middleton et al. 2015). Although the magnitudes varied, 12 severe *dzud* occurred during 1945–2010 (Middleton et al. 2015). One such disaster occurred in the winter of 2009–2010, causing total livestock mortality of about 20% across the country (Sternberg 2010). Damages were particularly severe (52% mortality) in Dundgovi Province (Fig. 1), affecting more than 50% of herder households (Sternberg 2010; UNCTR 2010). Since livestock is the main asset for herders in Mongolia (Nakamura et al. 2017), these livestock reductions represented a huge economic loss and led to out-migration from the countryside to towns and urban areas (Sternberg 2010; Nakamura 2019; Xu et al. 2021; Roeckert and Kraehnert 2022). Because the pastoral system in Mongolia has a relatively simple relationship between the environment and society, it is suitable for an examination of the trend of economic inequality after an extreme climate event, such as a *dzud*.

Our objective was to empirically investigate the changes in economic inequality before and after an extreme climate event by analyzing a decade-long dataset at the household level. Mongolia conducts an annual census of livestock numbers per household, and we used the dataset for 2004–2013 to investigate changes in economic inequality among herders preceding and following the 2009 winter disaster.

Methods

Study area

Our study area is in Dundgovi Province, which is located in the Gobi region in Mongolia. One of the most important reasons we chose Dundgovi Province as a study site is because pastoralism in Dundgovi was heavily damaged by a winter

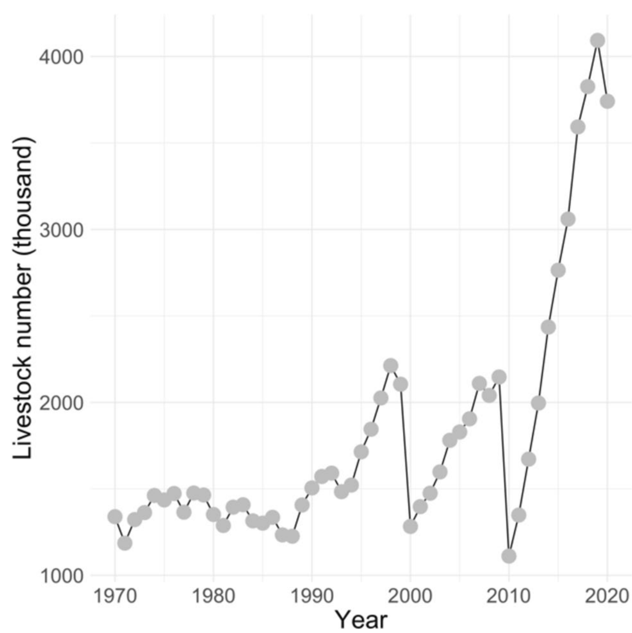

Fig. 1 Annual total number of livestock in Dundgovi Province, 1969–2020. Data from the Mongolian Statistical Information Service (http://www.1212.mn/)

disaster in 2009–2010 (Du et al. 2018; Nakamura et al. 2017; Rao et al. 2015). The number of livestock decreased by 52% in 2010 and did not recover until 2013 (Fig. 1). Therefore, it is suitable to examine the impact of climate extremes on economic inequalities in this region.

Mean annual precipitation in Dundgovi Province was 158.2 mm during 1901–2020 (data from the Climate Change Knowledge Portal, https://climateknowledgeportal.worldbank.org/country/mongolia/climate-data-historical). Changes in climatic variables are shown in Figure S1. The area lies in the steppe ecological zone (Hilbig 1995), and the main livestock types are camel, sheep, goat, horse, and cattle. Sheep and goat are the main types of livestock, with 49% and 37% of the mean annual total number of livestock from 1960–2020, respectively, followed by horse (8%), cattle (4%), and camel (2%) (data from the Mongolian Statistical Information Service). Mean annual number of herder households was 8899 from 1991–2020 in Dundgovi Province (data from the Mongolian Statistical Information Service).

Livestock data

The number of livestock is often used as an indicator of household economic condition in Mongolia (e.g., Kakinuma et al. 2019; Nakamura et al. 2017). In 2009, 74% of the average household income was derived from livestock production, 21% from social security (e.g., a pension), and 4% from non-livestock production in Saintsagaan, which is located in the study area (Nakamura 2020). Because most herders rely on livestock production as their primary income source, we assumed the number of livestock was a proxy of economic level for herder households.

The Mongolian government conducts an annual census of livestock numbers per household every December. During this census, the head of each village visits households to record the number of livestock per household. The data collected from villages are managed by sums (counties). For our research, we visited sum offices and obtained data for research from Saintsagaan, Gurvansaikhan, and Ulziit sums in Dundgovi Province during 2004–2013 (Table 1), provided they agreed with our research objective. All personal information was converted into numbers, and individuals could not be identified. The dataset includes the number of livestock by type (camel, horse, goat, sheep, and cattle) in each household for a given year. The total number of households in the dataset is 2254. To obtain long-term panel data, we extracted households that were in the study areas during the entire study period (2004–2013). In addition, we also extracted households that resided in the area before the disaster (2004–2009). In total, we extracted 787 of the 2254 households. We included households that were in the study area before the disaster (but not after), because we assumed they probably stopped engaging in pastoralism and/or left the local area after the disaster. We regarded the number of livestock of such households as zero in the absence of any other data after 2010. Nakamura (2020) reported that 45 of 138 investigated households quit pastoralism in this area after the disaster, and most of them moved to urban or suburban areas.

Table 1 Mean number of households and number of sampled households in the three study counties

County	Mean number of households (2004–2013)	Sample size
Saintsagaan	1006	282
Gurvansaikhan	556	282
Ulziit	526	223

For comparison purposes, we converted each livestock type into sheep units (SU). A sheep unit represents the feed requirement of one sheep per year: one camel equals five SU, one horse is seven, one cow or bull is six, and one goat is 0.9 (National Statistics Office of Mongolia et al. 2019). The total number of SU was then calculated for each household for each year. The SU is widely used in Mongolian rangeland research to calculate livestock number when there are several livestock types (e.g., Rao et al. 2015; Nakamura et al. 2017).

Measuring inequality

We used the Gini coefficient, a widely used measure of socio-economic inequality, to measure economic inequalities among herders (Sitthiyot and Holasut 2020). The coefficient is derived from Lorenz curves (Lorenz 1905), which plot economic distribution. A value of 0 indicates perfect equality and 1 indicates maximum inequality (Sitthiyot and Holasut 2020). We calculated the Gini coefficient for each year during 2004–2013 by using total livestock number (SU: Sheep Unit) per household.

Measuring impact and recovery by household economic group

Decomposition of inequality by household economic group

To examine which household group contributes to total inequality, we categorized households into economic groups and conducted a decomposition analysis of inequality. We categorized households into three economic groups, high-SU ($n = 234$), middle-SU ($n = 275$), and low-SU ($n = 278$), based on the number of livestock (SU) they possessed in 2009, a year before the disaster. The high-SU group had more than 500 SU, the middle-SU had 200–500 SU, and the low-SU had less than 200 SU. Nakamura (2020) suggested that 300 SU is a threshold for recovery from the disaster. We adjusted the number from 300 to 200 SU, so that the samples would be more equally distributed among the groups. The adjustment was made as the original threshold might have resulted in uneven group sizes due to the distribution of livestock numbers among the households. A more evenly distributed sample size is crucial for our decomposition analysis to prevent potential bias from significantly different group sizes. We used general entropy measures (Bellu and Liberati 2006) to decompose inequality between and within household groups. Specifically, we utilized the mean log deviation (MLD) to decompose inequality. The MLD is useful in understanding economic inequalities (Cowell 2011). We calculated MLD for each group with R (Plat 2012).

Loss and recovery patterns by household economic groups

To examine loss and recovery patterns by economic level, we divided the three household economic groups into six groups based on whether they recovered their livestock number in 2013. If the livestock number in 2013 was larger than that in 2009, the household was categorized as recovered. If the livestock number in 2013 was smaller, it was categorized as damaged. Overall, there were six groups: high-SU recovery, high-SU damage, middle-SU recovery, middle-SU damage, low-SU recovery, and low-SU damage. For instance, the 'high-SU damage' group represents households that had a high number of livestock before the winter disaster, but failed to restore their livestock count to pre-disaster levels by 2013. We then calculated the average loss rate of each group as follows: loss rate = (SU2009 – SU2010)/SU2009, where SU2009 and SU2010 are the converted number of livestock (SU) in 2009 and 2010, respectively. We calculated the recovery rate of livestock for each group as follows: recovery rate = (SU2013 – SU2009)/SU2009, where SU2013 and SU2009 are the converted number of livestock (SU) in 2013 and 2009, respectively.

Results

Inequality trends

Annual Gini coefficients increased after the winter disaster, increasing from 0.46 in 2009 to 0.61 in 2010 (Fig. 2a). The coefficients were stable after the disaster, and it was still 0.61 in 2013. The distribution of livestock number per household changed after the disaster; the proportion of households with a low number of livestock increased after 2010 (Fig. S2). The Lorenz curves also showed a clear shift toward greater inequality after the disaster (Fig. 2b). The total number of livestock, however, increased after the disaster and recovered to the 2008 level by 2013 (Fig. S3). Taken together, these results indicate that the economy at the community level recovered after the disaster, but the distribution changed, as inequality within the community increased. We also simulated the trends of the Gini coefficient assuming that no winter disaster happened and compared it with observed data

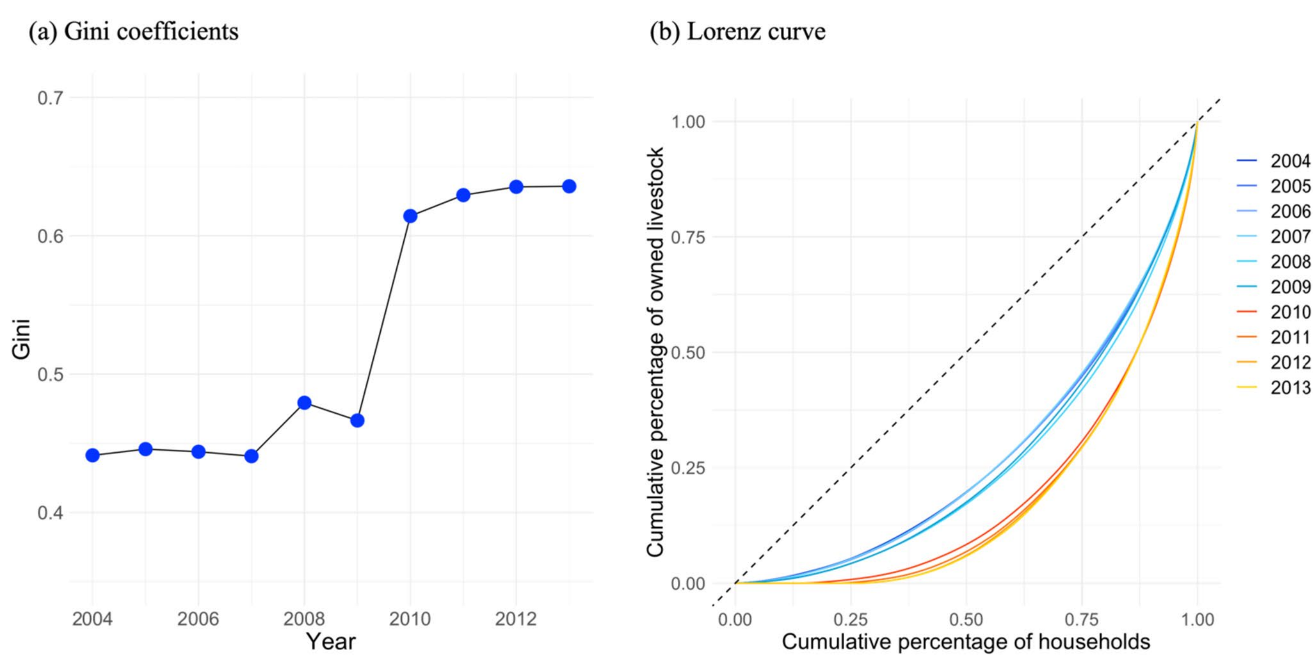

Fig. 2 Change in inequality among herders' households. **a** Gini coefficients for all study households, 2004–2013. **b** Lorenz curves. The winter disaster occurred in 2009. The dashed line in **b** represents perfect equality

(Figure S4). These results also support that the inequality was increased after the winter disaster.

What factors affected the expanding inequalities?

Decompositions of inequalities

Within-group inequality rather than between-group inequality largely increased after the disaster and greatly contributed to total inequality (Fig. 3a). In particular, inequality within households in the low economic group made the largest contribution to total inequality (Fig. 3b). The large number of dropped households (i.e., those with no livestock or no livestock records after the disaster) in the group had an impact on the results: 52.1% of households in the low-SU (i.e., economic) group were categorized as "dropped households", compared to only 17.8% and 8.9% in the middle and high-SU groups, respectively (Table 2). In addition, 28.4% of households in the low-SU group did not recover and only 19.4% recovered (Table 2). Contributions of inequalities in the middle and high-SU groups were smaller than that of the low-SU group throughout the period (Fig. 3b), although both of these groups also had increased within-group inequality after the disaster (Fig. 3b). In addition, the rate of recovered households in the middle- and high-SU groups was higher than that of the low-SU group. These trends explain the relatively small contributions in the medium and high economic groups to total inequality.

Table 2 Number of households that quit pastoralism after the disaster by household group

Household group	Total households	Recovered households (%)	Non-recovered households (%)	Dropped households (%)
High-SU	234	99 (42.3%)	114 (48.7%)	21 (8.9%)
Middle-SU	275	93 (33.8%)	133 (48.3%)	49 (17.8%)
Low-SU	278	54 (19.4%)	79 (28.4%)	145 (52.1%)
Total	787	249 (31.6%)	327 (41.5%)	215 (27.3%)

Loss and recovery rates by groups

The damaged groups include the dropped households (i.e., they are the sum of 'Non-recovered households' and 'Dropped households' in Table 2). Although all household economic groups saw a reduction in the mean livestock number in 2010 (Fig. 4a), their loss rates varied by group (Fig. 4b). The highest average loss rate was 74.6% in the low-SU damaged group, which also had the lowest average recovery rate (−78.9%, Fig. 4b). The results suggest that, in addition to the absolute number, the loss rate is also an important factor in the recovery from the disaster loss. All recovery groups had lower average loss rates (−32.4 to +27.3%) than all damage groups (50.9–74.6%). Interestingly, the lowest loss rate was observed in the low-SU recovery group (Fig. 4b), indicating that some households ($n=54$) with small numbers of livestock were able to improve their holdings despite the impact of an extreme weather event.

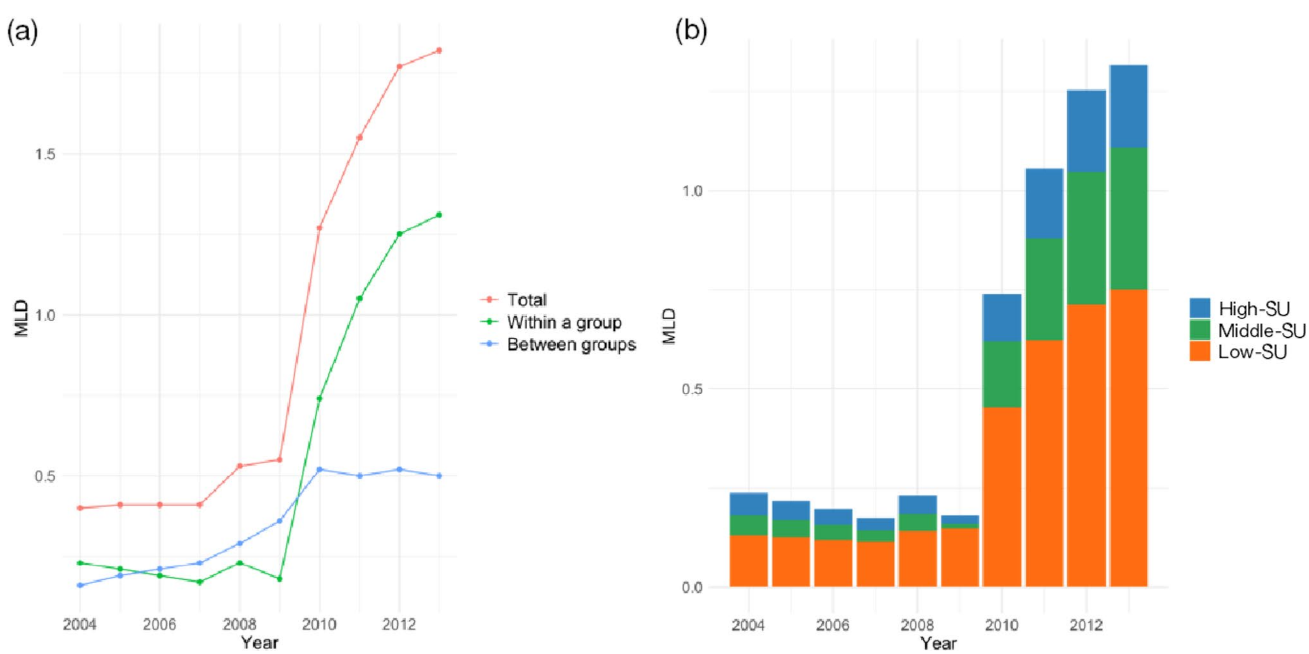

Fig. 3 Decomposition of inequality. **a** Mean log deviation (MLD) in the entire sample (total), within groups, and between groups. **b** Contributions to total inequality by each group

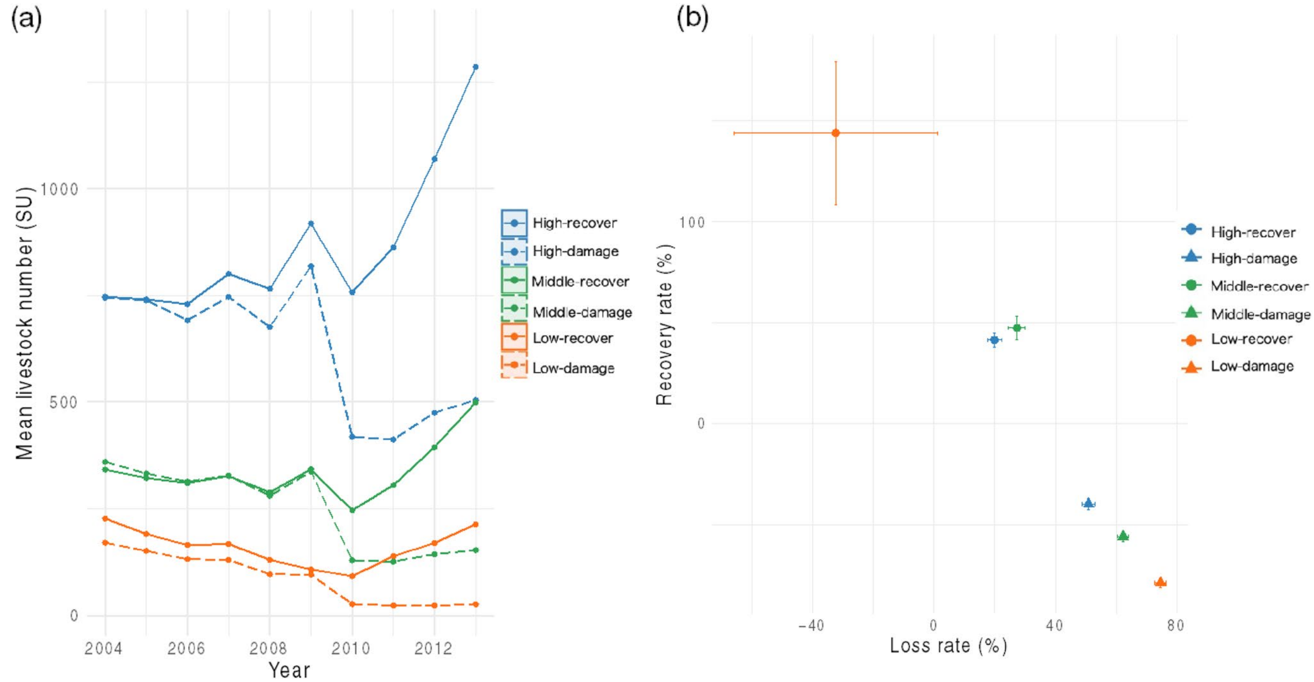

Fig. 4 Disaster response and recovery pattern by household economic group. **a** Change in average total livestock number (SU) by group during 2004–2013; **b** loss rate and recovery rate of livestock by group. Shadows in **a** indicate standard error. Points and bars in **b** indicate mean and standard error, respectively. Sample sizes are 99 (high-SU recover), 135 (high-SU damage), 93 (middle-SU recover), 184 (middle-SU damage), 54 (low-SU recover), and 224 (low-SU damage)

In addition, some middle- and high-SU level households did not recover their livestock numbers (Fig. 4a, b). These household groups saw a livestock reduction of more than 50%, and it was difficult to recover from such high losses. We also found that the low-SU recovered group had a larger mean livestock number than the middle-SU damaged group in 2013 (Fig. 4a). In fact, the low-SU recovered group had the largest recovery rate of all groups (Fig. 4b). Future studies are needed to explore factors that affect recovery of livestock number.

Discussion

The relationship between climate extremes and economic inequality is a crucial global issue of interest. However, their empirical evidences are still limited (Hallegatte and Rozenberg 2017; Palagi et al. 2022), since long-term panel datasets rather than snapshot datasets are required to assess economic distribution changes after an extreme climate event (Angelsen and Dokken 2018). In this study, we provide empirical evidence which indicates an expansion of economic inequality among herders in Mongolia after the winter disaster of 2009–2010 (Fig. 2) by analyzing a long-term household panel dataset. We found an increase of within-group inequality in households after the disaster (Fig. 3). The inequality within the low-SU group made a large contribution to total inequality (Fig. 3b). Specifically, 27.3% of total households had no livestock after the disaster (i.e., "dropped households" in Table2), with the low economic group being particularly affected, as 52.1% of households within this group were dropped households (Table 2). Nakamura (2019) also reported that 45 out of 148 households in Sainstagaan, which is one of our study areas in Dundgovi province, lost most livestock during the disaster in 2009–2010. They tracked these 45 households and investigated their occupations after the disaster. They found that 10 households had started a pension life, while the other 35 households had changed their occupations. Among the 45 households, none continued to engage in livestock production (Nakamura 2019). Thus, we assume that the majority of households listed as "dropped households" in Table 2 are no longer involved in pastoralism, with a few possible exceptions. These results suggested that households with a small number of livestock are more vulnerable than households with medium or large numbers of livestock. A study from pastoral systems in Ethiopia suggests that there may be a certain number of livestock below which recovery becomes challenging, potentially leading to a poverty trap (Lybbert et al. 2004). If there are large economic inequalities among households, impacts of upcoming disasters would be greater (Cappelli et al. 2021). Therefore, supporting households with a small number of livestock would be important to avoid such a vicious cycle between climate extremes and economic inequality.

We detected expanding inequality after the winter disaster in 2009 in Mongolia, and the increased level of inequality remained 4 years after the disaster (Fig. 2). This finding is in contrast to a study in Sri Lanka that did not detect expansions of inequality among households after disasters from 1990–2013 (Keerthiratne and Tol 2018). Keerthiratne and Tol (2018) pointed out the presence of diverse occupations (e.g., agricultural production or non-agricultural production) in Sri Lanka and that may have mitigated the expansion of inequality after disasters. On the other hand, pastoralism is a main agricultural industry in our study area, and herders' incomes largely rely on pastoralism (Nakamura 2020). In addition, we focused on the severe winter disaster instead of multiple disasters. In this context, when we refer to a "simple social–ecological system" such as that in Mongolia, we mean a system with less economic and occupational diversity compared to other regions. Thus, our results suggest that a simple social–ecological system such as that in Mongolia is likely to experience increased inequality after a disaster, whereas more complex social–ecological systems would be more diverse in their responses to climate extremes.

Our results suggest that reducing loss rates during a disaster, particular for households of low economic status, is important to alleviate the impacts of climate extremes on inequality. On average, the damaged household groups that did not recover their livestock number experienced a loss of 50.9–74.6% of their livestock, while those that did recover lost less than 30% (−32.4 to +27.3%) (Fig. 4). Further research is needed to determine the threshold for livestock losses that allow for recovery. However, it is probable that keeping livestock losses below a certain level during a winter disaster would facilitate the recovery of livestock numbers. In fact, households of low economic status, characterized by smaller livestock number, also recovered after the winter disaster ("Low-SU recover" in Fig. 4). Therefore, it is necessary to identify the measures taken by households with small numbers of livestock to mitigate the effects of damage and increase their livestock numbers after the winter disaster in our study areas. Government support for households in poor economic status to implement these measures may help prevent a significant reduction in livestock numbers during a winter disaster. Previous studies (e.g., Joly et al. 2018; Tachiiri et al. 2008) pointed out that poor body conditions of livestock interact with severe winter conditions and lead to large mortality of livestock in Mongolia. Therefore, preparing for a disaster during normal years, for example, by keeping fodder, repairing winter shelters, and supporting long-distance movement to fatten livestock (Du et al. 2018; Fernandez-Gimenez et al. 2015; Middleton et al. 2015; Soma and Schlecht 2018), may reduce the impacts of a disaster. However, these measures can be costly and place a financial burden on poor households (Ahearn 2018). Thus implementing government support to mitigate these costs may be helpful.

The results of this study also suggest the importance of looking at the overall economic distribution when assessing the economic impacts of climate extremes. Although the total number of livestock recovered after the disaster (Fig. 1), the economic distribution of the study area clearly changed (Figs. 2, 3). About 67% of sample households did not recover their livestock number after the disaster (Table 2), but almost 33% of households had large increases in the number of livestock. These results indicate that there is risk of underestimating the impacts of climate disasters on inequalities if only aggregated data are used to assess their economic impact. This point is particularly important when considering reducing poverty (SDG 1) because poor households are more vulnerable to disasters.

This study acknowledges certain limitations that warrant consideration. First, the study did not investigate the specific climatic factors responsible for the substantial livestock loss during the 2009 winter disaster. Although the primary focus was to observe trends in economic inequality among herders after a climate extreme event, understanding the underlying climatic causes might offer valuable insights for potential mitigation measures. It should be noted that existing research has identified a combination of factors, including summer drought, extreme winter cold and snow, as well as socio-economic factors, contributing to the occurrence of winter disasters (Tachiri et al. 2008; Rao et al. 2015; Nandintsetseg et al. 2018). Moreover, further research should explore the cumulative effects of disasters on livestock production, to provide a more comprehensive understanding of the issue. While our analysis demonstrated an intensification of economic inequality among herders in the selected areas, it should be noted that the severity of the 2009 winter disaster varied across different regions of Mongolia (Rao et al. 2015; Roeckert and Kraehnert 2022). Therefore, it cannot be definitively stated that the winter disaster of 2009 uniformly impacted all herder households across the country. However, our study highlights the potential for extreme climate events to exacerbate inequality among herders. Future research should explore the differential effects of climate extremes in various regions to provide a more comprehensive understanding of the issue at the national level.

Conclusions

We empirically showed the expansion of economic inequality among herders in Mongolia after a climate extreme event. We suggest that appropriate preparations during normal years, particularly support to poor households, would reduce loss rates during a disaster and mitigate the impacts of climate extremes on economic inequality. The impact of climate extremes on economic inequality is particularly important in areas where most households largely depend on a single agricultural activity, and extreme climate events may delay the goal of ending poverty and reducing economic inequality by 2030 (SDGs 1 and 10). It is essential to develop and implement adaptation measures for disasters during normal periods to stop the vicious cycle between extreme climate events and inequality (Cappelli et al. 2021).

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Data availability The datasets used in the figures in this paper are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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