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The Integrated Impact of Drought on Crop Yield and Farmers' Livelihood in Semi-Arid Rural Areas in China

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Abstract: Drought has a profound impact on crop yield and the subsistence farming economy in arid and semi-arid lands of developing countries. It creates insecurity in the food supply and livelihood of rural farmers, leading to different livelihood trajectories and transformations. However, a primary challenge is to examine the complexity and location-specificity of drought impact. This study proposes a conceptual framework to understand the integrated drought impact on Yuzhong County in Gansu Province, China. Specifically, the study applies the standardized precipitation index at different time scales to observe drought changes from 1960 to 2017 and estimates the correlation with crop yield. Then, farmers in the northern, central, and southern regions of Yuzhong County were categorized using two-step cluster analysis, based on survey data collected from 1013 interviews conducted in the three regions. The study explores the impact of drought on the livelihood and food security of different clusters of farmers and analyzes their livelihood trajectories and transformations. The results showed that the drastic years with moderate and severe droughts were 1981–1983, 1997, and 2011–2012. Drought was significantly correlated with crop yield, and the effect of SPI12 was more severe. Five clusters of farmers in the southern regions of Yuzhong county were affected by drought with large drought disaster areas and serious economic losses, leading to high rates of affordability deficit and food insecurity, especially in the southern region. As a result, farmers have been adapting their livelihoods to drought, transforming toward mixed livelihoods in the northern region and part-time agricultural livelihoods in the central and southern regions. This study recommends an increase in public investment in water conservancy and irrigation facilities and suggests that locations and policies be utilized to promote the transformation of farmers' livelihoods to make them more resilient.

Keywords: drought-integrated impact; crop yield; farmers' food and livelihood security; livelihood transformation; China

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Citation: Shi, Y.; Zhao, L.; Zhao, X.; Lan, H.; Teng, H. The Integrated Impact of Drought on Crop Yield and Farmers' Livelihood in Semi-Arid Rural Areas in China. *Land* **2022**, *11*, 2260. https://doi.org/10.3390/land11122260

Academic Editor: Dingde Xu

Received: 19 October 2022
Accepted: 8 December 2022
Published: 10 December 2022

1. Introduction

Drought is a major global natural disaster affecting human society today [1]. Arid regions of the world have continued to expand due to global warming. The severity and frequency of droughts have significantly increased [2,3], causing a marked reduction in crop production, considerable socio-economic losses in agriculture, and food security in the arid and semi-arid regions of developing countries [4–7]. Over the past 60 years, droughts have caused an annual grain output reduction of 16.159 billion kilograms and annual economic loss of $12.8 billion in China [8,9]. Agriculture is the main source of livelihood in rural communities of arid and semi-arid regions of China, where drought is one of the most damaging natural hazards [10,11]. Thus, farmers are the most direct victims of drought, with the reduced crop yields cause huge economic losses that have catastrophic effects on the livelihood security of rural families [8,12–14]. It is essential to study the impact of drought on agricultural production, the livelihood of farmers, and food security in order to achieve the second Sustainable Development Goal of the United Nations in the rural areas of developing countries [15].

Drought has a multi-dimensional impact on agricultural systems and rural families owing to its complex and uncertain characteristics with high spatial and temporal variability [16,17]. However, one-dimensional measurements are commonly used to analyze the impact of drought on crop yield or farmer livelihood in studies. In recent years, many studies have been conducted on crop yields, maize yields, wheat yields, and the like at different spatial scales, including global [18,19], national [20–22], and regional scales [23,24], analyzing the relationship between crop yield and drought indices, such as the standardized precipitation index (SPI) [15,25]. Several regional scale studies have focused on the northeast and northwest regions of China [26–28]. In addition, the impact of drought on the livelihood of farmers has also received considerable attention from researchers. They have investigated income loss and food security through farmer interviews and questionnaire data, respectively [5,12–14,29]. Notably, rural communities are the main areas affected by drought and farmers are the main stakeholders in agricultural production. The impact of drought on the agricultural system and farmer livelihood systems is multidimensional and multi-scale. However, few studies have assessed integrated drought impact, especially in the arid and semi-arid regions of developing countries. It is difficult to systematically evaluate the integrated drought impact due to data limitations. Nevertheless, understanding the integrated impact is critical for policymakers and stakeholders to effectively mitigate and adapt to drought [30].

Owing to geographical locations, environments, and drought mitigation measures, the temporal and spatial distribution characteristics of drought impact on crop yield are significantly different in various regions [31]. This results in geographical variations in farmers' vulnerability to drought; droughts with the same intensity and severity have distinct effects on farmer livelihoods in different local regions [5]. Therefore, this study analyzed the impact of drought on crop yield and farmer livelihood in rural communities of Yuzhong County in Northwest China from an integrated perspective, using SPIs at different time scales, correlation analysis, and statistical analysis with multi-source data. The study aims to address the gap in the multi-scale impact of drought, better understand the multidimensional impact of drought, and contribute to effective drought management strategies. In particular, the objectives of this study are as follows: (1) identify drought characteristics at different time scales and temporally and spatially analyze the relationship between drought and crop yield using the standardized precipitation index (SPI); (2) compare drought disaster areas, economic loss, livelihood affordability, and food security after drought among different clusters of farmers using interviews and questionnaire data; and (3) describe the transformation of farmer livelihoods and their trajectories in regions with different crop plantings.

2. Analytical Framework to Assess the Integrated Impact of Drought

Analytical frameworks to assess the impact of drought on agricultural systems and rural families obviously differ. Numerous models and surveys have been used separately to analyze the effects of drought on crop yield and livelihood systems. Specifically, scholars have used a systemic approach to identify the impact of drought on the structure of agricultural dynamic loops with elements of drought, water resources, the growth process of crops, crop production, and the agricultural economy [32]. They have also analyzed the impact of drought on farmer livelihood within the analytical framework of sustainable livelihood [33]. However, this study places greater emphasis on the direct impact of drought on crop yield, farmer livelihood, and food security at the county scale and in rural communities than other studies. Hence, the analytical framework needs to integrate a wide range of drought temporal and spatial variations along with their relationship with crop yield and farmer livelihood [34]. In this study, the analytical framework supposes that drought directly impacts crop yield, which in turn determines farmer livelihood and food security, leading to the transformation of farmer livelihoods. Whereas drought indirectly impacts farmer livelihood by affecting crop yield, farmer livelihood transformation also indirectly impacts crop yield with agricultural labor migration. On this basis, the analytical framework identifies temporal changes of drought and assesses the direct impact on crop yield, farmer livelihood, and food security using correlation analysis and statistical analysis methods, and depicts the transformation of farmer livelihoods and their trajectories with precipitation data, statistical data, and farmer surveys.

SPI is commonly used to assess and monitor drought [16]. In this study, SPI was computed at 6, 12, and 24 month scales to analyze drought variation. Accordingly, the correlation between drought and crop yield was determined. Next, the impact of drought on farmer livelihood and food security was analyzed by interviewing farmers, investigating the area affected, and assessing the economic losses caused by drought to the farmers and the adequacy of food for family households. Finally, farmer livelihood transformation is the outcome of the impact of drought on their livelihoods and also the response of farmers to drought (Figure 1).

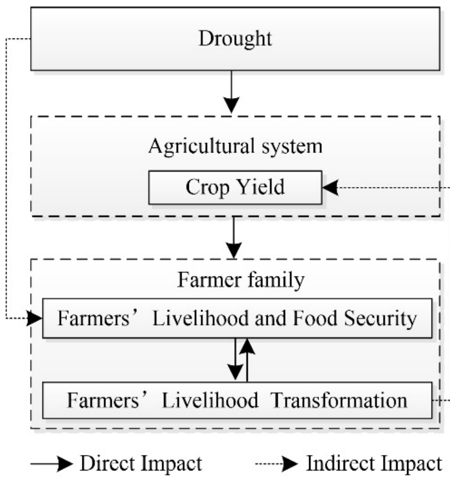

Figure 1. The analytical framework of the integrated impact of drought in rural areas.

3. Materials and Methods

3.1. Study Area

Rural areas in semi-arid regions of Northwest China are characterized by frequent drought disasters, water scarcity, fragile ecology, and high-density poverty. Villages in semi-arid areas are involved in various agricultural production activities. Drought has long been the most important natural disturbance factor for the area's development and is the most important limiting factor for local agricultural production and rural economic development [35–37].

Yuzhong County is located in Gansu Province, a semi-arid area in Northwest China. It has a land area of 3302 km^2 (103°50′–104°34′ E and 35°34′–36°26′ N) and is situated on the Loess Plateau of Longxi, which has complex variations in the frequency, duration, and magnitude of drought [38]. The average annual precipitation in Yuzhong County is approximately 328 mm. Moreover, the precipitation distribution is uneven due to large differences in altitude and decreases from north to south. The county also frequently witnesses extreme drought events [39].

A large proportion of the economy in Yuzhong County is agricultural. There are three types of agricultural districts with different topographies (Figure 2), namely the northern mountainous agricultural district, the central irrigated agricultural district, and the southern mountainous agricultural district. These districts have distinct agricultural activities, irrigation facilities, and infrastructure, leading to significant differences in the integrated impact of drought.

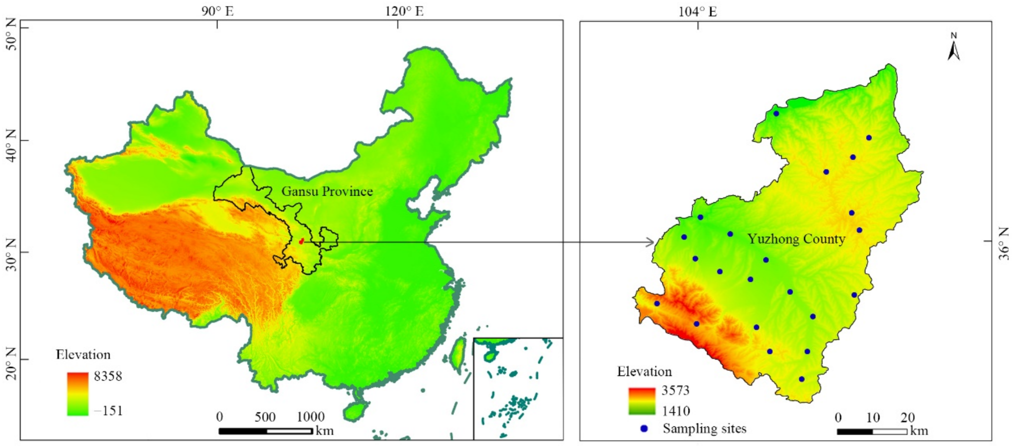

Figure 2. Location and survey sites in the study area.

3.2. Data Collection and Sampling

The data used in this study included meteorological, statistical, and questionnaire survey data. Meteorological data pertaining to daily precipitation and daily temperature was collected by the Yuzhong meteorological station from 1960 to 2017 and downloaded from the China Meteorological Data Service Center (http://cdc.cma.gov.cn) accessed on 19 November 2019. Statistical data were collected from The Yuzhong County Statistical Abstract (2002–2017) and the Yuzhong County Agricultural Statistics Annual Report (2002–2017). All questionnaire survey data were obtained using a stratified random sampling method in pre- and formal surveys. The pre-survey of farmers suffering from drought in the three agricultural districts was conducted in July 2016. Based on problems identified in the pre-survey, a formal survey of farmers from the three agricultural areas was conducted in June 2017, covering 22 townships and 85 administrative villages in Yuzhong County. Finally, 1013 valid questionnaires were obtained.

3.3. Methods

3.3.1. SPI

SPI is commonly applied in the fields of climatology, meteorology, and agriculture to monitor and analyze drought for different time scales [40,41]. Therefore, SPI is used to assess the impact of drought on crop yields [15,39]. Previous studies have detailed the SPI calculation process [25,42]. The drought intensities and categories are listed in Table 1.

Table 1. SPI drought category classification [13,29,30].

SPI	Categories
≥2.0	Extremely wet
1.5∼1.99	Severely wet
1.0∼1.49	Moderately wet
0.0∼0.99	Slightly wet
0.0∼−0.99	Slightly drought
−1.00∼−1.49	Moderately drought
−1.50∼−1.99	Severely drought
≤−2.0	Extremely drought

3.3.2. Correlation Analysis

The correlation coefficient is a measure of the drought impact on crop yield in semi-arid regions [6]. Accordingly, the Pearson correlation coefficient was used to evaluate the effect of drought on crop yield with a significance threshold of $p < 0.05$ in Yuzhong County [43]. This study analyzed the relationship between SPI (SPI6, SPI12, and SPI24) and crop yield from 2000 to 2017 due to limited data on crop yield.

3.3.3. Two-Step Cluster Analysis

Two-step clustering is a statistical analysis method that reflects the distinctness of natural clusters within a dataset and automatically identifies the number of clusters [44]. This method facilitates the analysis of mixed attribute datasets with categorical and continuous variables and has the advantage of being able to process massive amounts of data with automatic standardization. The two-step clustering process consists of two steps: pre-cluster and formal cluster. First, a cluster feature tree is constructed and divided into many subclasses. Then, the clusters completed in the first step are re-clustered using the hierarchical clustering method [45].

4. Results

4.1. Time Variability of Drought Characterization

SPI was calculated at three time scales (6, 12, and 24 months) from 1960 to 2017. Figure 3 shows the time variability of SPI6, SPI12, and SPI24 at the Yuzhong station. There were significant differences at different time scales; the larger the time scale, the more obvious the change in drought intensity. Figure 3 depicts that slight drought was the common drought category over Yuzhong County between 1960 and 2017. However, the degree and duration of drought progressively increased with the time scale of SPI. Specifically, moderate droughts occurred only in 1997 and 2011 at SPI6; in 1981, 1982, and 2011 at SPI12; and in 1983, 2003, 2011, and 2012 at SPI24. In particular, the SPI24 was −2.239 in 1982, indicating that an extreme drought occurred in 1982.

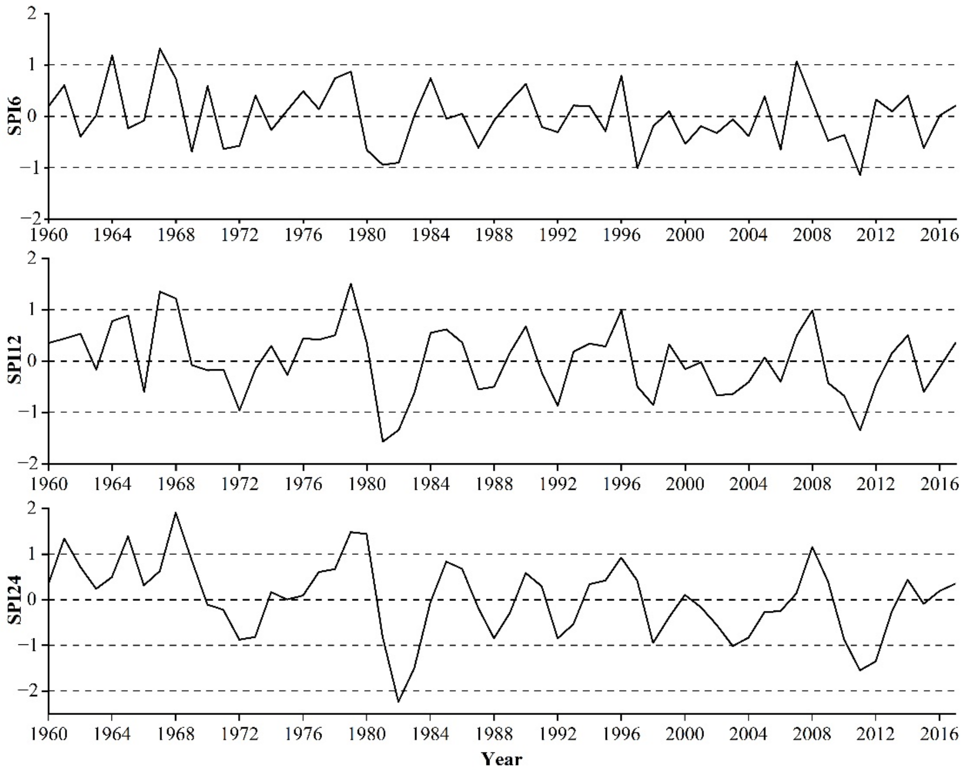

Figure 3. SPI time series variability at different time scales from 1960 to 2017.

4.2. Correlation Analysis between Drought and Crop Yield

The relationship between SPI6, SPI12, SPI24, and crop yield was analyzed to assess the influence of drought on crop yield. As shown in Table 2, there was positive correlation between SPI6, SPI12, SPI24, and crop yield from 2000 to 2017 in Yuzhong County. The correlation coefficients between SPI6, SPI12, SPI24, and crop yield were 0.563, 0.636, and 0.512, respectively, with a p-value of less than 0.05 in the significance test, indicating that crop yield was significantly affected by drought. Additionally, the highest correlation coefficient was observed between SPI12 and crop yield, indicating that SPI12 had a more significant impact on crop yield than SPI6 and SPI24.

Table 2. The correlation coefficients between SPI6-24 and crop yield in Yuzhong county.

Variable	SPI6		SPI12		SPI24	
	Coefficient	***p***	**Coefficient**	***p***	**Coefficient**	***p***
Crop yield	0.563 *	0.023	0.636 **	0.008	0.512 *	0.042

** significant at the1% level; * significant at the5% level; $n = 18$.

To spatially analyze differences in the relationship between drought and crop yield in towns throughout Yuzhong County, correlation coefficients and significance maps from 2000 to 2017 were generated using ArcGIS 10.2 (Figure 4). The results showed that SPI6, SPI12, and SPI24 were significantly correlated with crop yield in most towns of Yuzhong County. Moreover, there were significant spatial differences in the impact of drought on crop yield in towns at different correlation coefficient intervals. Particularly, there are 19 towns with correlation coefficients between 0.5 and 0.8 for SPI12, decreasing to 17 and 12 towns for SPI6 and SPI24, respectively, showing that SPI12 had the most significant effect on crop yield in different towns compared to SPI6 and SPI24.

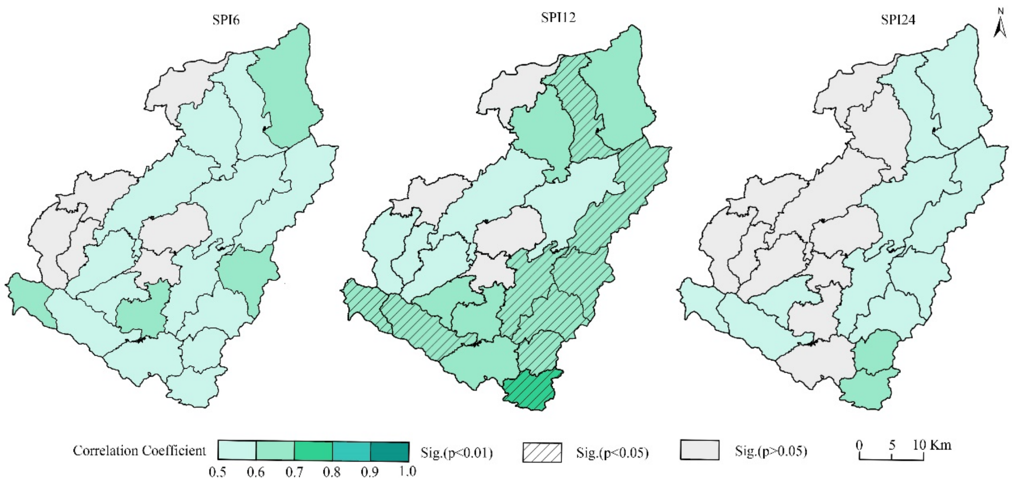

Figure 4. Spatial distribution of correlation coefficients between SPI and crop yield in towns of Yuzhong county.

4.3. Drought Impact on Different Types of Farmer Families

4.3.1. Classification of Farmer Type

Farmer livelihoods diverge owing to differences in terrain, irrigation facilities, and economic conditions in Yuzhong County. Drought has varying effects on different various types of farmers. To statistically evaluate the drought impact on the disaster area, economic loss, and food security of different farmers, two-step cluster analysis was used to classify the farmers. The best cluster results were determined by the highest value of the Bayesian information criterion (BIC), BIC variation, BIC variation rate, and distance measurement ratio. Table 3 shows that the BIC, BIC variation, BIC variation rate, and distance measurement ratio values were high when there were five clusters in the two-step cluster analysis results. Hence, farmers in Yuzhong County were divided into five categories based on the two-step cluster analysis.

Table 3. Parameters of two-step cluster analysis.

Clusters	BIC Value	BIC Variation	BIC Variation Rate	Distance Measurement Ratio
1	8696.169			
2	7780.617	−915.551	1.000	1.389
3	7152.637	−627.980	0.686	1.014
4	6534.977	−617.660	0.675	1.199
5	6038.183	−496.794	0.543	1.540
6	5754.417	−283.765	0.310	1.197
7	5535.556	−218.861	0.239	1.327
8	5397.924	−137.633	0.150	1.035
9	5268.643	−129.281	0.141	1.388
10	5206.383	−62.260	0.068	1.001
11	5144.219	−62.164	0.068	1.012
12	5084.182	−60.036	0.066	1.109
13	5040.904	−43.278	0.047	1.094
14	5010.874	−30.031	0.033	1.040
15	4986.252	−24.622	0.027	1.157

Table 4 presents the characteristics of the farmer categories. There were significant differences between the northern, central, and southern regions of Yuzhong County in terms of sample numbers and proportion of total farmers in each category. The first, second, and third clusters of farmers had the largest numbers of farmers, accounting for more than 30%, respectively; the sample number of the fifth cluster was 120, accounting for 33.333%.

Table 4. Characteristics of farmer categories of different regions in Yuzhong county (N = 1013).

Clusters	Northern Region		Central Region		Southern Region	
	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)
1	78	31.837	26	7.222	71	17.402
2	17	6.939	140	38.889	57	13.971
3	58	23.673	37	10.278	159	38.971
4	43	17.551	37	10.278	81	19.853
5	49	20.000	120	33.333	40	9.804
Total	245	100.000	360	100.000	408	100.000

4.3.2. Impact of Drought on Economic Loss and Farmer Livelihood

To identify differences in the effect of drought on the five clusters of farmers from the three regions in Yuzhong County, this study analyzed the impact of drought on the disaster area, economic loss, and farmer livelihood security using the two-step clustering method. The descriptive statistics are shown in Table 5.

Compared to the central and the northern regions of Yuzhong County, the five clusters of farmers in the southern region were affected by the largest drought disaster area (mean: 5.2 acres) and suffered the most severe economic losses (mean: CNY 6878.6). In particular, the first cluster of farmers in the southern region had the highest economic loss of CNY 10,642 with a drought disaster area of 7 acres, which was related to the highest drought disaster area and cash crop planting (vegetables). Additionally, the economic losses of the second, fourth, and fifth clusters of farmers were higher than those of the northern and central regions of Yuzhong County. In the northern and central regions, the second cluster of farmers had the most severe economic loss. In particular, the second cluster of farmers in the central region with the smallest drought disaster area (two acres) had the largest economic loss (CNY 6547) because cash crop (vegetable) planting yields much higher economic income than other crops. The second cluster of farmers in the northern region also suffered the highest economic loss (CNY 8676.471) and had the largest drought-affected area (5.412 acres).

Table 5. Result of the impacts of drought on disaster area and economic loss.

Regions	Clusters	Drought Disaster Area		Economic Losses Due to Drought	
		Mean	Standard Deviation	Mean	Standard Deviation
Northern region	1	2.801	3.144	4847.436	5048.925
	2	5.412	6.993	8676.471	9922.712
	3	3.000	5.507	5060.000	7586.210
	4	5.000	7.617	5888.000	7994.201
	5	3.000	5.341	5796.000	7895.362
Central region	1	3.000	4.657	5923.077	5585.145
	2	2.000	3.195	6547.000	8552.541
	3	3.000	4.240	5854.000	7079.650
	4	2.000	3.910	3541.000	4622.377
	5	2.000	3.166	6108.000	8571.914
Southern region	1	5.000	5.532	3906.000	4719.803
	2	4.000	4.218	6049.000	7476.753
	3	7.000	5.666	10,642.000	9973.207
	4	4.000	4.468	6183.000	6234.335
	5	6.000	6.295	7613.000	8381.793

Because the five clusters of farmers in the three regions of Yuzhong County suffered heavy economic losses, we analyzed the impact of drought on farmer livelihood security. All farmers were asked the following question: "Do you still have economic affordability after the economic loss?" According to Table 6, many farmers' livelihoods were vulnerable to drought. The percentages of those who answered "Yes" was 33.061%, 20.001%, and 33.824% in the northern, central, and southern regions of Yuzhong County, respectively. In addition, the percentage of those who answered "Yes" in the fourth cluster of farmers was the highest among all three regions.

Table 6. Impact of drought on farmer livelihood security.

Regions	Clusters	With Economic Affordability		Without Economic Affordability	
		Frequency	Percentage (%)	Frequency	Percentage (%)
Northern region	1	45	18.367	32	13.061
	2	11	4.490	6	2.449
	3	58	23.673	0	0.000
	4	0	0.000	43	17.551
	5	49	20.000	0	0.000
Central region	1	21	5.833	5	1.389
	2	112	31.111	28	7.778
	3	37	10.278	0	0.000
	4	0	0.000	37	10.278
	5	118	32.778	2	0.556
Southern region	1	42	10.294	29	7.108
	2	29	7.108	28	6.863
	3	159	38.971	0	0.000
	4	0	0.000	81	19.853
	5	40	9.804	0	0.000

4.3.3. Impact of Drought on Farmer Food Security

Due to the large area of drought in the three areas of Yuzhong County and the poor harvest of crops, drought directly affects the food security of farmers. When asked: "Is there enough food for your family after the reduction in food production?" According to Table 7, the percentage of those who answered "No" was 55.918%, 67.778%, and 80.391% in the north, central and southern regions respectively, indicating that the drought resulted in food insecurity in all three regions, especially in the southern region. Farmers in the second to fifth clusters all reported food insecurity problems.

Table 7. Impact of drought on farmer food security.

Regions	Clusters	Food Security		Food Insecurity	
		Frequency	Percentage (%)	Frequency	Percentage (%)
Northern region	1	78	31.837	0	0.000
	2	13	5.306	4	1.633
	3	1	0.408	57	23.265
	4	0	0.000	43	17.551
	5	16	6.531	33	13.469
Central region	1	26	7.222	0	0.000
	2	61	16.944	79	21.944
	3	0	0.000	37	10.278
	4	0	0.000	37	10.278
	5	29	8.056	91	25.278
Southern region	1	71	17.402	0	0.000
	2	11	2.696	56	13.725
	3	1	0.245	158	38.725
	4	0	0.000	81	19.853
	5	7	1.716	33	8.088

4.3.4. Farmer Livelihood Transformations and Trajectories

Farmer livelihood trajectories were constructed through in-depth semi-structured interviews in Yuzhong County. Respondents were asked about past crop growth, crop production, and sources of income [46]. Farmer interviews revealed that they used to have similar livelihoods based on agriculture. However, with the expansion of urbanization in Lanzhou city and policies such as rural revitalization in the neighboring provincial city of Gansu Province, the livelihoods of farmers had transformed from being completely agriculture-based to those based on a mixture of a part-time agricultural livelihoods, mixed livelihoods, off-farm livelihoods, and employed livelihoods. Additionally, differences in resource conditions among the three regions, such as topography, precipitation, and infrastructure, further contributed to livelihood diversity.

The classifications of livelihood transformations and trajectories in terms of the five livelihood strategies were distinguished as per Novotny et al. [46]. These included agricultural livelihoods, part-time agricultural livelihoods, mixed livelihoods, off-farm livelihoods, and employed livelihoods. Based on the actual situation of farmer incomes in the study area, there were types I–V of part-time agricultural livelihood, namely "cash crop and labor income", "food crop and labor income," "cash crop income and self-employed income", "cash crop and wage income", and "food crop and self-employed income", respectively. Additionally, there were types I–III of agricultural livelihoods, including "cash crop income", "food crop income", and "cash crop and food crop income".

As shown in Figure 5, there were differences in the trajectories and scales of the livelihood transformations across the three regions. The livelihoods in the northern region were transformed mainly into mixed livelihoods depending on the income from grain crops and cash crops such as lilies and medicinal materials, as well as self-employment and part-time labor employment in proximity to townships and counties. Meanwhile, most farmers mainly had the first type of part-time agricultural livelihood in the central and southern regions, since they were engaged in cash crop planting (vegetables) and part-time employment. Compared to the above, the proportions of other livelihood transformation outcomes were relatively low.

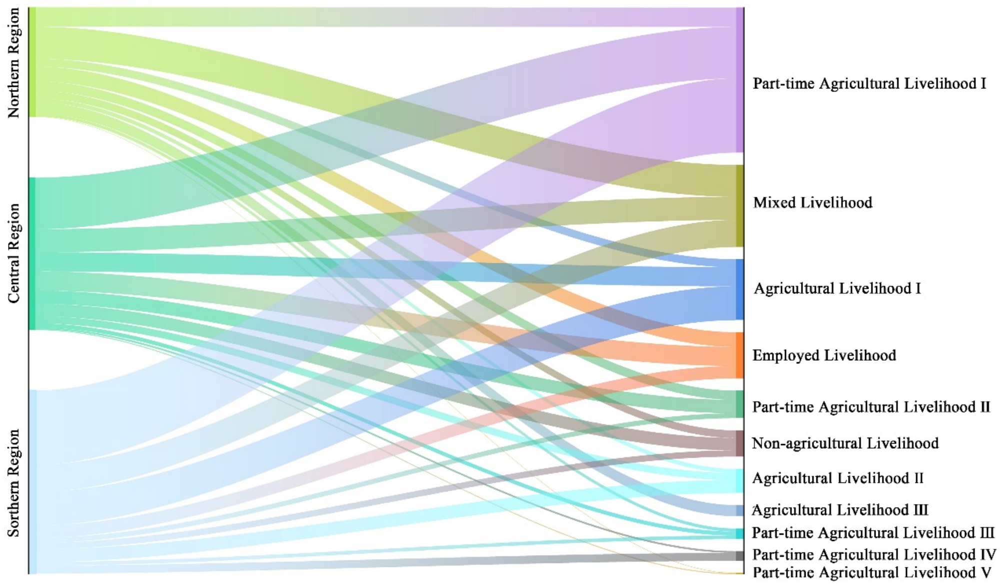

Figure 5. Farmer's livelihood transformations and trajectories in Yuzhong county.

5. Conclusions, Discussion, and Policy Implications

Drought poses a significant threat of poor agricultural production and economic loss, especially to farmer incomes and food security, which are the primary sources of livelihood and food for the majority of farmers in arid and semi-arid regions. Therefore, it is critical to understand the complexity of drought impact. In this study, we proposed a drought-integrated analytical framework identifying the exposure of Yuzhong County to drought from 1960 to 2017 using SPI6, SPI12, and SPI24, and examined the impact of the spatial and temporal characteristics of drought on crop yield. Our study highlighted the impact of drought on different cluster types of farmers in terms of economic loss, livelihood, food security, and adaptation to drought through livelihood transformation. The results showed as follows:

The years with moderate and severe drought were 1981–1983, 1997, and 2011–2012. The correlation coefficients between SPI6, SPI12, SPI24, and crop yield from 2000 to 2017 were 0.563, 0.636, and 0.512, respectively, indicating that drought with SPI12 had a more severe impact on crop yield. In addition, SPI6, SPI12, and SPI24 were significantly correlated with crop yield in most towns of Yuzhong County at the spatial scale. The results indicated that slight droughts were common in Yuzhong County, but the drought events significantly impacted crop yield in Yuzhong County and most of its townships, causing sensitivity of crop yield to drought.

Five clusters of farmers in the three regions of Yuzhong County were affected by drought with a large drought disaster areas and serious economic losses, resulting in an affordability deficit and food insecurity for farmers. These effects were more severe in the southern region, with an average drought disaster area of 5.2 acres, economic loss of CNY 6878.6, affordability deficit of 33.824%, and food insecurity of 80.391% due to the large arable land area, high altitude, and poor water conservancy facilities. Thus, farmers in the southern region of Yuzhong County are more vulnerable to drought than those in other regions.

Farmer livelihoods have transformed in all three regions of Yuzhong County. The trajectories of livelihood transformations have moved toward mixed livelihoods in the northern region and part-time agricultural livelihoods in the central and southern regions. The high altitude, low vegetation cover, and poor soil quality result in low crop production in the northern region of Yuzhong County; thus, traditional agriculture is unable to increase the financial capital of farmers in this region, whereas mixed livelihoods contribute to enhanced livelihood resilience to drought. Conversely, farmers in the central and southern regions have engaged in cash crop planting, for which the income is higher than for traditional crop planting.

Due to data limitations and the absence of consistent timing of survey data, only crop yields from 2000–2017 could be used in this study to correlate with SPI. Future research can focus on studying the integrated impact of drought on agricultural systems and farmer livelihood in arid and semi-arid regions in China at a larger spatial and temporal scale. In addition, drought vulnerability and farmer livelihood vulnerability can be further assessed based on this study. The analytical framework of socio-ecological system resilience could be applied to explain rural socio-ecological system adaptations to drought in terms of drought resilience and farmer livelihood resilience.

To reduce the multi-dimensional impact and vulnerability of drought in Yuzhong County and narrow the gap between the drought impacts on the northern, central, and southern regions, it is necessary to increase the investment in water conservancy and irrigation facilities. In addition, Yuzhong County could use its location and policy advantages to promote the transformation of farmer livelihoods to non-agricultural livelihoods in the urban sub-center of Lanzhou city in Gansu Province. Meanwhile, there are national 4A scenic spots in the south of Yuzhong County, which could support the development of rural tourism. We recommend that local managers organize tourism planning to guide the participation of local farmers in tourism service activities so that they may find a new source of livelihood, thus increasing farmer livelihood resilience to cope with the negative impacts of drought.

Author Contributions: Conceptualization, methodology, and data collection and analysis, Y.S. and L.Z.; Writing—Original Draft Preparation, Y.S.; Writing—Review and Editing, Y.S. and X.Z.; visualization and supervision, Y.S. and H.T.; funding acquisition, H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Natural Science Foundation of China (grant number 42001268) and the Northwest Normal University Young Teachers' Scientific Research Ability Promotion Program (grant number NWNU-LKQN2020-17).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data of this study are available on request from the corresponding author.

Acknowledgments: We would like to thank all authors and the Key Laboratory of Resource Environment and Sustainable Development of Oasis, Northwest Normal University, for their support of this study.

Conflicts of Interest: The authors declare no conflict of interest.

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