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Evaluation of Sustainable Livelihoods in the Context of Disaster Vulnerability: A Case Study of Shenzha County in Tibet, China

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Abstract: The issue of achieving sustainable livelihoods (SL) is a persistent problem that has gained significant interest for all countries. Even though contexts of vulnerability have been highlighted to be critical to SL, the difference of SL under vulnerability contexts, particularly disaster, has been ignored. As one disaster-prone area, there is an urgent need to conduct studies on SL in Shenzha, within the context of the construction of a national park. This paper proposes to address this research gap by evaluating SL under various disaster contexts in Shenzha, China. According to the frequency of natural disasters, towns in Shenzha can be divided into three groups: Snowstorm and windstorm-dominated towns (SWT), mixed towns (MT) and drought-dominated towns (DT). The results showed that (1) a great disparity of SL can be observed among the three vulnerability groups. The scores of these SL were sorted into descending order as: DT > SWT > MT. (2) In detail, herdsmen in DT have a high value of SL because they have high livelihood assets, livelihood strategies and disaster management capabilities. (3) Herdsmen in SWT have high livelihood assets, particularly human and financial assets, and livelihood strategies. (4) The low livelihood assets and livelihood strategies have restricted the SL of herdsmen in MT. An analysis of SL under various disaster contexts helped to depict the characteristics of SL. Accordingly, targeted policies were developed for the development of SL under various disaster contexts.

Keywords: sustainable livelihoods; disaster vulnerability; livelihood asset; livelihood strategy; disaster management

1. Introduction

The long-lasting climate change on a global scale will continue to change for decades, at rates projected to be unprecedented in human history [1]. Global climate change research in recent years has seen increasing interest in livelihoods enhancement [2]. Livelihoods are a combination of resources, which include capabilities, assets and activities that are necessary for the support of living activities [3,4]. Even though the rate of global poverty has been decreased sharply since 2000, the issue of livelihoods is a persistent issue worldwide. Livelihoods are considered to be sustainable only if they can cope with and recover from stress and shocks, as well as maintain and strengthen assets, activities and capabilities without destroying the natural resource base [5]. Studies on sustainable livelihoods (SL) have direct implications in achieving the Sustainable Development Goals (SDGs), which is a global development agenda issued by the United Nations (UN) in 2015 [6].

Recent years have seen rising interests in sustainable livelihood approaches in order to understand the accessibility of livelihood assets to different households [4,5,7]. The most commonly used framework for these studies is the sustainable livelihoods framework (SLF), which was established by the United Kingdom's Department for International Development (DFID) [8] (Figure 1). In the framework, there are five main components, including vulnerability context, livelihood assets, transforming structure and processes, livelihood strategies and outcomes. Specifically, the vulnerability context refers to the external environment which is vulnerable. In general, it can include shocks, trends and seasonality, which are beyond the control of people. Livelihood assets include five forms of assets, which are human (H), physical (P), social (S), financial (F) and natural (N) assets. The choices that people make and the activities that people undertake in order to achieve their livelihood goals are mentioned as livelihood strategies.

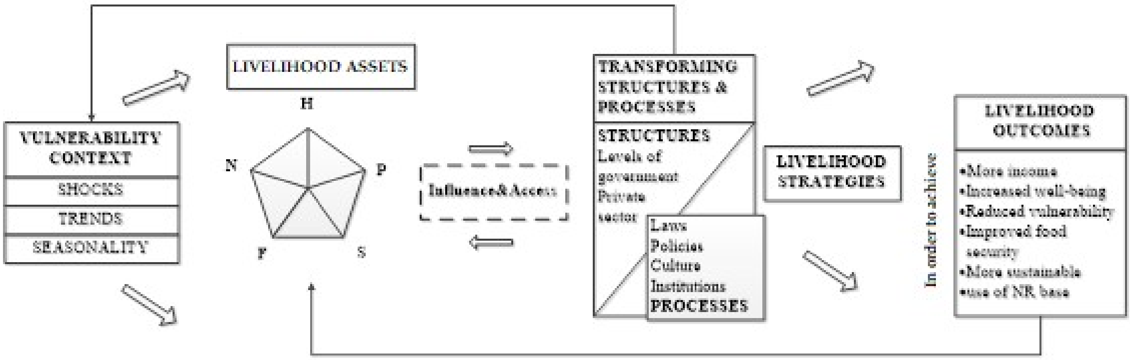


Figure 1. The sustainable livelihoods framework of the United Kingdom's Department for International Development (DFID).

In general, the current studies on SL focus on three main research agendas from a geographical perspective. The first agenda is to address the relations among the five components. Under certain vulnerability contexts, livelihood strategies can always be adopted in order to seek livelihood assets and outcomes [9,10]. Transforming structures and processes can affect all elements at a high level by determining the availability of resources, thus affecting the exchange conditions among livelihood assets and strategies [11]. The second research agenda focuses on assessing SL and its temporal and spatial differences. The key components can always be identified, and thus help to understand SL and provide development references for policy assessment [12,13]. The third research agenda is to address external factors' impact on SL and their components. In particular, environmental changes, land use and rural tourism have been well-examined to have great impacts on SL [14,15].

It is the second research agenda that we aim to address in this analysis. While reviewing the literature on the livelihood sustainability index (LSI), the most commonly used indicators are mainly based on livelihood assets and strategies [16]. Even though vulnerability contexts have been highlighted to be critical to SL, the literatures on the difference of SL under vulnerability contexts are thin. In general, vulnerability can be defined in a number of ways, depending on the multi-disciplinary context [17]. Among these, one of the widely accepted definitions is that vulnerability is the ability or inability of individuals or social groupings to respond to, cope with, recover from, or adapt to, any external stress placed on their livelihoods and well-being [18,19]. Moreover, vulnerability has been functioned by sensitivity, exposure unit and adaptive capacity [20]. The exposed factors (e.g., climate disasters) have made profound impacts on agriculture in the form of increased crop pests and disease outbreaks, frequency and severity of droughts, high livestock mortality and reduced yields [21]. What is worse, is that the vulnerability of poor and mountain-dwelling people is sensitive, because of their associations with natural systems [22]. Adaptation ensures quality and functional out-production, maximizing profit, positive changes of attributes on a system and long-term sustainability [20]. In this context, livelihood assets and strategies will be different because of the difference in vulnerability.

Therefore, depicting the characteristics of SL to the vulnerability to various disasters is an important step in reducing vulnerability and accelerating resilience.

Climate change's impact on rural populations in developing countries is apparent, since their main livelihoods are constituted by agriculture and many other components [18]. Shenzha County, located in the most economically-undeveloped province (Tibet) in China, has the highest incidence of poverty, with a high proportion above 18.06% [23]. Population has increased rapidly, with the average annual growth rate of 26.89% in Shenzha County. Shenzha is a typical husbandry county where grassland is the dominant ecosystem type, accounting for more than 81.52% of the total land area [24]. Herdsmen there traditionally depend upon agriculture and animal husbandry for survival. However, influenced by changeable climate and disasters which are largely shaped by the complex terrain and atmospheric circulation [25,26], recent decades have seen a serious problem of grassland degradation in the Tibetan Plateau [27,28]. What is worse than this, is that snowstorms, combined with other environmental stressors, such as drought and windstorms, have led to extremely harsh conditions for livestock grazing, and even a high livestock mortality rate [29–31]. Rapid population growth, poverty, grassland degradation and climate disaster have intensified vulnerability in this county. As a result, the impacts of climate disasters in Shenzha have already led to great loss in agriculture and animal husbandry. Moreover, according to the report by the International Panel on Climate Change, winter precipitation in most parts of the Tibetan Plateau will continually increase [32]. Therefore, the increasing frequency of natural disasters is foreseeable, and thus will cause more challenges for the sustainable livelihoods of herder communities in Tibet.

The aim of our analysis is to evaluate the SL in Shenzha under diverse disaster contexts based on the SLF. Our analysis has three main research contents: (1) First, we divide the disaster vulnerability into three contexts, according to the occurrence probability of common disasters in Shenzha. (2) Then we construct a series of sustainable livelihood indices (SLI), which are applied in disaster contexts. (3) The SL and their main components under various vulnerability contexts are compared. Carrying out the SL evaluation of herdsmen communities has a practical significance for reducing vulnerability and avoiding livelihood risks for herdsmen. The rest of the paper is divided into four main sections as follows: Section 2 introduces the methodology used in this paper. Section 3 reports on the main results. Section 4 discusses the main results, as well as some of the limitations of our analysis. The last section finishes by giving the main conclusions of our analysis. Moreover, the policy implications based on the research results are also discussed in the last section.

2. Methodology

2.1. Overview of the Study Area

Shenzha County is located in the south of the Qinghai-Tibet Plateau (Figure 2). It is located at the east longitude 87°33′ and the north latitudes 30°10′~32°10′. The total area of the county is 25,500 square kilometers (about 9,845.6 square miles). The terrain in Shenzha is high in the south and low in the north, with an average elevation of over 4700 m. Shenzha County governs eight towns: Shenzha Town, Xiongmei Town, Mayue Town, Maiba Town, Tarma Town, Xiaguo Town, Ka Town and Bazha Town.

Shenzha County was chosen as the case study because of two considerations: (1) Shenzha County, belonging to the semi-arid type of plateau sub-frigid zone with windy weather, is one of the typical areas with the worst climatic conditions in China. Various vulnerability contexts can be seen in Shenzha County. The annual average temperature is 0.2 °C, the highest temperature is 25.1 °C, the extreme minimum temperature is −30.1 °C and the average annual precipitation is 299 mm. Due to the unstable geological structure, high altitude, high mountainous terrain and steep terrain, Shenzha County faces the risk of various disasters, mainly windstorms, snowstorms and drought. (2) The proportion of herdsmen in Shenzha County accounts for more than 90% of the total population. Frequent disasters have caused great threats to the development of husbandry in Shenzha County [33].

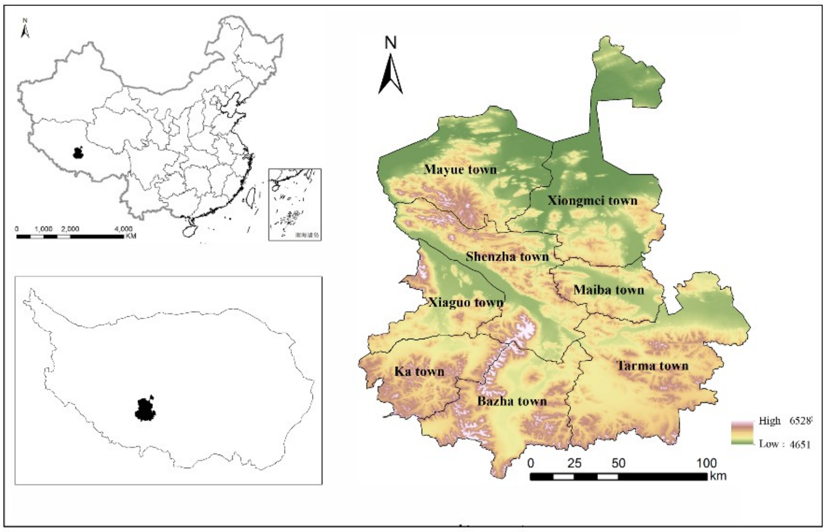


Figure 2. Location of Shenzha County.

2.2. *Analysis Framework*

2.2.1. Disaster Contexts in Shenzha

Drought, snowstorms and windstorms have been the main disasters in Shenzha County. Precipitation in Shenzha County is much less than evaporation, thus leading to the frequent occurrence of drought. The drought has led to a decline in grass production and a lack of pasture and water to support the survival of livestock. Moreover, once a snowstorm occurs, the grassland is covered by snow, and a layer of ice shell forms upon the surface. As a result, livestock are unable to eat grass any more. What is worse, the hunger and severe cold cause a large number of livestock to die, greatly affecting the development of animal husbandry. Northern Tibet, where Shenzha County is located, is one of the regions with the largest number of windy days in China. The strong wind erosion and accumulation have caused grassland areas to become wind-eroded and buried. As a result, the sustainable livelihoods (SL) of herdsmen communities have been threated greatly. For instance, the heavy snowstorm that occurred in 1997 has caused great loss to Shenzha County. According to the statistics, there were 16,314 livestock deaths and 13,013 people lacked fuel. Furthermore, 2,435 herdsmen had insufficient grain to survive, 1,953 herdsmen suffered from frostbite, eight people were disabled, 773 people suffered from influenza, 842 people suffered from typhoid fever and 618 people suffered from urticaria (hives) [34].

Considering the complexity (type and frequency) of disaster contexts in Shenzha County, our analysis applied the clustering method, which is the process of partitioning a given set of patterns into disjoint clusters [35]. K-means clustering is one of the most classic algorithms, and a large number of case studies have shown its excellent clustering effect [36]. This algorithm is a partition-based clustering algorithm, with distance as the criterion for the similarity measure between data objects. Given the data set P ∈ $R_m * n$ and the number of clusters K, K-means clustering makes the difference within the class as small as possible, and the difference between classes as large as possible. It can be obtained by the following formula [37]:

$$\min(\mathrm{E}) = \min \sum_{k=1}^{k} \sum_{x \in Y_k} (y_k - x)^2 \quad (1)$$

where Y_k is the kth group, y_k is the centroid in the kth group, and x is a point in the kth group.

2.2.2. Construction of Livelihood Sustainability Index

Critical attributes and variables which are related to SL are necessary to be identified before constructing a livelihood sustainability index (LSI). During the field survey, we found that basic livelihood needs (e.g., clothing, shelter, infrastructure (roads, buses, electricity)) were mostly satisfied, and showed little disparity among the selected towns. Livelihood assets, including human assets, natural assets, physical assets, social assets and financial assets, are the key components according to the British Department for International Development (DFID), and thus were chosen in our analysis. Moreover, livelihood strategy is one of components developed in the DFID. While livelihood diversification has been well-examined to be a sustainable pathway, most researchers have also proven that non-farm income is critical to sustainable livelihood strategies [38,39]. Besides, the frequent occurrence of disasters in Shenzha County has caused great loss of assets. Therefore, disaster management capabilities are critical to rural sustainability and food security in Shenzha County. Disaster management capability is particularly important in our analysis. Our analysis selects storage indicators to ensure the survival of human beings (e.g., food and fuel) and livestock (e.g., forage grass), in case of a disaster. Thus, three pivotal components—livelihood assets, livelihood strategies and disaster management capability—were selected (Table 1). Finally, we obtained key attributes and proxy variables to measure the SL of Shenzha County.

Table 1. Sustainable livelihoods (SL) framework-based indicators for assessing the livelihood sustainability index (LSI).

Major Components	Sub-Components	Proxy Indicators and Weights	Descriptions
Livelihood assets (E1)	Human assets (0.1294)	Number of laborers (0.0651)	Able-bodied = 1, semi-able-bodied workers = 0.5
		Gender of laborers (0.0643)	Male laborer = 0.59, Female laborer = 0.41
	Natural assets (0.1224)	Grassland (0.0606)	Grassland area (Mu/per capita)
		Fenced grassland (0.0618)	Fenced grassland (Mu/per capita)
	Physical assets (0.1213)	Livestock assets per capita (0.0586)	1 cow = 0.85, 1 horse = 0.05, 1 sheep = 0.1
		Equipment assets per capita (0.0627)	1 truck = 1, 1 car = 0.8, 1 tractor = 0.8, 1 motorcycle = 0.8
	Social assets (0.1998)	Township cadres (0.0726)	Township cadres per household
		Health technical persons (0.0647)	Health technical persons per household
		Veterinarian (0.0625)	Veterinarians per household
	Financial assets (0.1232)	Primary industrial income per capita (0.0575)	
		Non-primary industrial income per capita (0.0657)	
Livelihood strategies (E2)	Diversification of livelihoods (0.0634)	Number of livelihood activities (0.0634)	
	Non-agricultural livelihoods (0.0622)	Ratio of non-agricultural employment (0.0622)	
Disaster management capability (E3)	Human survival storage (0.1213)	Grain per capita (0.0589)	
		Fuel per capita (0.0623)	
	Livestock survival storage (0.0623)	Forage grass per sheep (0.0571)	Forage ratio conversion: 1 cow = 5 sheep, 1 horse = 6 sheep, 1 goat = 0.8 sheep

Note: The unit of land area in China is the Mu; 1 Mu = 0.1647 acres (where one acre = 4,840 square yards = 0.404686 hectares = 4,046.86 square meters).

2.2.3. Entropy Method

After choosing the indicators of SL, the entropy method, which is based on Shannon's Entropy Method, was applied to determine weights for each indicator [40]. The concept of entropy is to measure the relative intensities of contrasting criteria to represent the average intrinsic information for decision-making [41].

Our analysis uses the entropy method to determine weight in order to eliminate subjective factors. In general, the higher the entropy, the more balanced, and the less fluctuation there will be in the system structure. On the contrary, lower levels of entropy mean more unevenness and greater differences in the system structure. The main steps are as follows:

(1) Data standardization: Due to the dimensional difference of each index, the initial data need to be standardized. Adopting the positive index calculation method, the result showed that the bigger the index, the better the system development.

$$X'_{ij} = (X_{ij} - \min(X_j)/(\max(X_j) - \min(X_j)). \quad (2)$$

(2) The value of the *i*th town and the *j*th indicator is:

$$Y_{ij} = X'_{ij} / \sum_{i=1}^{m} X'_{ij}. \quad (3)$$

(3) The value of the information entropy is:

$$E_j = -k \sum_{i=1}^{m} (Y_{ij}) * (\ln Y_{ij}),\ k = \frac{1}{\ln m},\ 0 \le e_j \le 1. \quad (4)$$

(4) The redundancy value of information entropy is:

$$d_j = 1 - e_j. \quad (5)$$

(5) The index value is:

$$w_j = d_i / \sum_{i=1}^{n} d_j. \quad (6)$$

(6) The score of a single index in the *k*th group is:

$$S_{kj} = w_j * X'_{kj}. \quad (7)$$

The comprehensive sustainable livelihood score in the *k*th group is:

$$S_k = \sum_{j}^{n} S_{kj}. \quad (8)$$

Here, X_{ij} represents the original value of the *i*th town and the *j*th indicator. The $\max(X_j)$ and $\min(X_j)$ represent the maximum and minimum values in the *j*th indicator among all towns. X'_{kj} is the standardized indicators in the *k*th group, and m is the number of towns being assessed, while n is the number of the indicators. Here, m = 8 and n = 16.

2.3. Data Source

The data issue has been the main obstacle, since the dataset in Tibet has been either unavailable or in poor quality. We conducted the investigations on the local area several times, and obtained valuable data from various sources. During data collection, our analysis was supported by the local government, who provided us with a lot of valuable data (e.g., annual reports, statistical yearbooks, atlases, county annals). In addition, we visited local research departments in order to further complete our database. The main data sources are tracked in Table 2.

Table 2. Data sources of main indicators in Shenzha County.

Indicators	Data Sources
Number of laborers	Annual Production Report of Farming and Animal Husbandry in Shenzha, Xiongmei, Mayue, Maiba, Tarma, Xiaguo, Ka and Bazha Towns.
Gender of laborers	
Area of grassland	
Area of fenced grassland	
Livestock assets per capita	

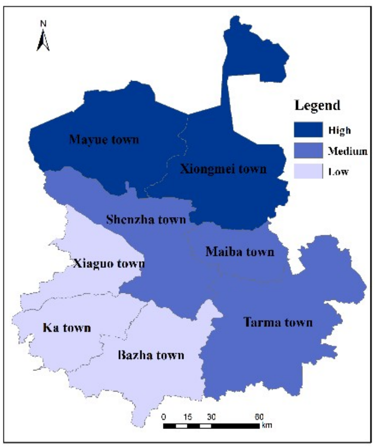
Table 2. *Cont.*

Indicators	Data Sources
Equipment assets per capita	
Township cadres	
Health technical persons	
Veterinarians	
Primary industrial income per capita	
Non-primary industrial income per capita	
Number of livelihood activities	
Ratio of non-agricultural employment	
Grain per capita	
Fuel per capita	
Forage grass per sheep	
Population	China County Statistical Yearbook 2017 [42].
Income per capita	Shenzha County Yearbook 2017 [43].
Nation/province/county	National Catalogue Service For Geographic Information (www.webmap.cn).
Township boundaries	Tibet Autonomous Region Atlas 2012 [44].
Disaster data	Regionalization of Animal Husbandry of Naqu Region [33].
Qinghai-Tibet Plateau boundaries	Global Change Research Data Publishing & Repository [45].
Digital Elevation Model (DEM)	Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences (The data set is provided by Geospatial Data Cloud site, Computer Network Information Center, Chinese Academy of Sciences. (http://www.gscloud.cn).

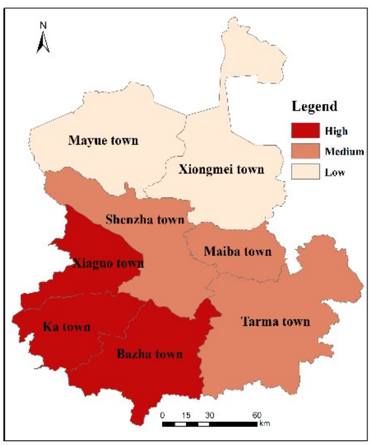
3. Result

3.1. Disaster Contexts in Shenzha

In terms of snowstorms, Mayue Town and Xiongmei Town had the highest degree of vulnerability, followed by Shenzha Town, Maiba Town and Tarma Town (see Figure 3a). The lowest degree of vulnerability was held by Xiaguo Town, Ka Town and Bazha Town. The degree of snowstorm proneness showed a trend from north to south. Referring to drought, the distribution trend was opposite that of snowstorms (see Figure 3b). Xiaguo Town, Ka Town and Bazha Town had the highest occurrence of drought. The lowest degree of drought was found in Mayue Town and Xiongmei Town, indicating a decreasing trend from south to north. In terms of windstorms, the number of windy days showed a decreasing trend from northwest to southeast (see Figure 3c). Tarma Town had the lowest occurrence of windstorms. In comparison, Xiongmei Town, Mayue Town, Shenzha Town and Xiaguo Town had the highest occurrence rates of windstorms.

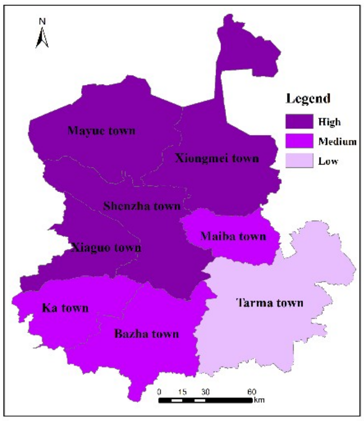


(**a**) Snowstorms.



(**b**) Drought.

Figure 3. *Cont.*



(**c**) Windstorms.

Figure 3. Vulnerability contexts in Shenzha County.

With the application of K-means, disaster contexts can be divided into three groups: Snowstorm and windstorm-dominated towns (SWT), mixed towns (MT) and drought-dominated towns (DT) (Figure 4). The results showed that SWT were mainly distributed in the north of Shenzha County, including Shenzha Town, Xiongmei Town and Mayue Town. MT were mainly distributed in the east of Shenzha County, including Maiba Town and Tarma Town. DT were mainly distributed in the west of Shenzha County, including Xiaguo Town, Ka Town and Bazha Town.

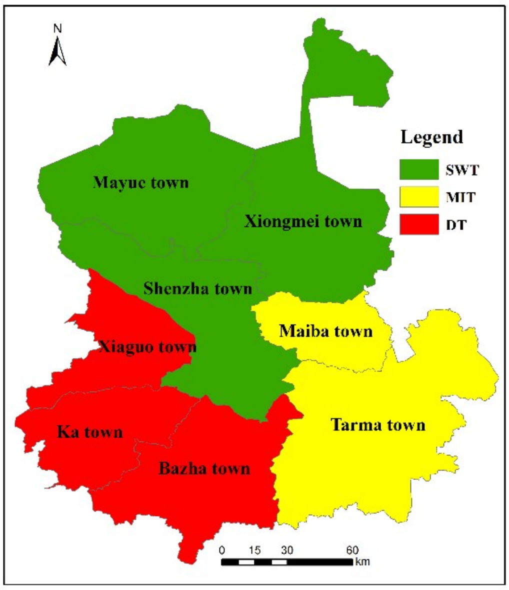


Figure 4. Vulnerability contexts in towns.

3.2. Livelihood Assets

In sum, livelihood assets showed great disparity among the three vulnerability groups (Table 3). Herdsmen in DT and SWT had relatively high values of livelihood assets: 3.5931 and 3.4870, respectively. In comparison, herdsmen in MT had the lowest livelihood assets value (3.622), which was 6.47% lower than those in SWT and DT, respectively.

Table 3. Results of livelihood assets in vulnerability groups and original indicators.

Group	Human Assets	Natural Assets	Physical Assets	Social Assets	Financial Assets	Livelihood Assets
Snowstorm and windstorm-dominated towns (SWT)	0.7956	0.5842	0.5620	0.9117	0.6335	3.4870
Mixed towns (MT)	0.5886	0.6236	0.5137	1.0579	0.5769	3.3607
Drought-dominated towns (DT)	0.5575	0.6277	0.7434	1.0273	0.6373	3.5931

3.2.1. Human Assets

For the perspective of the overall human assets index, the results showed that there were large disparities among the three groups. In particular, herdsmen in SWT had the highest value, followed by MT and the lowest value in DT. This is related to the household laborers (Table 4). Two variables were selected to represent human assets: The number of laborers and the gender of laborers, which measure the human assets from the perspective of both labor quantity and quality. Households in SWT and DT both presented high numbers of laborers in general, and male laborers in particular, indicating both a high quantity and quality of human assets. In comparison, the values in MT were relatively low, and thus indicating low human assets.

3.2.2. Natural Assets

Looking at natural assets, the results showed that there were minor differences among the three groups. The natural assets of herdsmen in MT were the highest, while those in SWT were the lowest. Two variables were selected to represent natural assets: Grassland area and fenced grassland area, which measure the quantity and quality of grassland. In general, fenced grassland areas are of higher quality than normal grassland, and thus can lead to high livestock productivity. Therefore, although herdsmen in DT had the lowest grassland area (only 1,215 Mu/per capita), the fenced grassland per capita area (306 Mu/per capita) was the highest (Table 4). Even though herdsmen in MT own the lowest area of fenced grassland area, the large area of grassland compensated this factor to some extent. In detail, herdsmen in MT had the highest grassland area (1,549 Mu/per capita) and lowest fenced grassland area (145 Mu/per capita). As a result, herdsmen in DT and MT had high natural assets. In comparison, herdsmen in SWT had neither high grassland area, nor fenced grassland area, thus leading to the lowest value of natural assets.

3.2.3. Physical Assets

Two variables were selected to reflect the physical assets of herdsmen: Livestock assets and equipment assets. In sum, a great disparity in the physical assets was observed. For the overall physical asset index, herdsmen in DT had the highest physical assets, followed herdsmen in SWT and MT, in that order. The general rank sequences were the same for livestock assets and equipment assets. For instance, the indices of livestock and equipment assets of herdsmen in DT were 6.402 and 0.134, respectively, indicating both the highest average livestock assets and equipment assets (Table 4). In contrast, the livestock and equipment assets of herdsmen in MT were 4.363 and 0.099, being 31.85% and 26.12% lower than that values in DT, respectively.

3.2.4. Social Assets

Minor differences were observed for the overall social asset index. The values for SWT, MT and DT were 0.9117, 1.0579 and 1.0273, respectively. Three indicators, including township cadres, health technical persons and veterinarians, were selected. The general rank sequence was not consistent with the three selected variables. Moreover, large disparities were seen in the selected variables among the three groups. In detail, the township cadres per household in the three groups were 0.123, 0.174 and 0.161, respectively, indicating large differences. In comparison, health technical persons per household in the three groups were 0.030, 0.038 and 0.033, indicating minor differences among the three groups.

Table 4. Description of indicators of livelihood assets for different vulnerability groups in Shenzha County, China.

Group	Laborers	Gender of Laborers	Grassland	Fenced Grassland	Livestock	Equipment	Township Cadres	Health Technical Persons	Veterinarians	Primary Industrial Income	Non-Primary Industrial Income
SWT	2.292	1.271	1312	203	4.904	0.105	0.123	0.030	0.039	10,511	17,110
MT	2.114	1.152	1549	145	4.363	0.099	0.174	0.038	0.035	11,352	15,499
DT	2.093	1.131	1215	306	6.402	0.134	0.161	0.033	0.038	12,139	15,566

3.2.5. Financial Assets

Minor disparities were seen concerning financial assets. The scores of financial assets for the three groups were sorted in descending order as: DT > SWT > MT. In general, financial assets are consistent with livelihood strategies. Two variables were selected to represent the financial assets: Primary industrial income and non-primary industrial income. However, great disparities were observed among them. The primary industrial income in the three groups was sorted in descending order as: DT > MT > SWT. In detail, influenced by snowstorms, herdsmen in SWT had the lowest husbandry income of 10,511 yuan (circa 1,520 US Dollars), being 7.4% and 13.4% lower than those in MT and DT. In contrast, the non-primary industrial income in the three groups was sorted in descending order as: SWT > DT > MT. In detail, the herdsmen in SWT had highest non-primary industrial income, 17,110 yuan (circa 2,475 US Dollars). In comparison, the herdsmen in DT had relative high husbandry productivity, leading to the highest primary income and financial assets among the three groups. Meanwhile, the herdsmen in MT had an intermediate income.

3.3. Livelihood Strategies

In the face of different disaster contexts, herdsmen from different towns showed great disparities in the arrangement of livelihood activities (Table 5). In general, the livelihood strategy index was sorted in descending order as: DT > SWT > MT. A high value of the livelihood strategy index indicates flexible livelihood strategies. Herdsmen in DT and SWT had similar values (0.7072 and 0.6938), which were much higher than herdsmen in MT (0.4833). Moreover, the general rank sequence was consistent with the selected two variables, which were the diversification of livelihoods and non-agricultural livelihoods.

Table 5. Livelihood strategies for different vulnerability groups in Shenzha County, China.

Group	Diversification of Livelihoods	Non-Agricultural Livelihoods	Livelihood Strategy Index
SWT	0.3489	0.3450	0.6938
MT	0.2440	0.2393	0.4833
DT	0.3582	0.3490	0.7072

3.3.1. Diversification of Livelihoods

The results show that the diversification of livelihoods under various disaster contexts was quite different. Specifically, herdsmen in DT and SWT had the most various livelihoods, with values of 0.3582 and 0.3489, respectively. In comparison, herdsmen in MT had the least diverse livelihoods with the value of 0.244, being 32% lower than that in DT. Herdsmen in DT and SWT had high values because there are opportunities to engage in diverse livelihoods. For instance, about 12% of herdsmen engage in the construction industry, 5% in transportation and 10% in retailing services.

3.3.2. Non-Agricultural Livelihoods

The general rank of non-agricultural livelihoods was consistent with that in the diversification of livelihoods: DT > SWT > MT. The values under the three disaster contexts were 0.349, 0.345 and 0.2393, respectively (Table 6). Similarly, herdsmen in DT and SWT had high values because there was a large proportion (more than 31%) of herdsmen that engaged in non-farm activities, such as construction industry, transportation and retailing services, as described above.

Table 6. Disaster management capability and original indicators.

Group	Index	Grain Per Capita	Fuel Per Capita	Forage Grass Per Sheep
SWT	0.8832	242.544	117.206	2.292
MT	0.8956	170.382	122.585	3.429
DT	0.8960	177.634	117.512	16.245

3.4. Disaster Management Capability

Minor disparity was seen in reference to disaster management capability. The disaster management capability in DT was the highest, while that in SWT was the lowest (Table 6). Even though a minor disparity was observed among the three vulnerability groups, a great disparity could be observed when tracking back to the original indices. Two variables were selected to represent the disaster management capability: storage of grain, fuel and forage grass.

Moreover, large disparities were seen in the selected variables among the three groups. The grain storage in the three groups was sorted in descending order as: SWT > MT > DT. The fuel storage in the three groups was sorted in descending order as: MT > DT > SWT. The storage of forage grass in the three groups was sorted in descending order as: DT > MT > SWT. Once disaster occurs, livestock in SWT and MT will be more vulnerable than that in DT. In sum, SWT had quite a high amount of grain storage, MT had quite a high amount of forage grass storage, and DT had a high amount of fuel storage, indicating great disparities in coping with disaster across the vulnerability contexts.

3.5. Livelihood Sustainability Index

A great disparity in LSI was observed among the three vulnerability groups (Table 7). The scores of the LSI for the three groups were sorted in descending order as: DT (5.2) > SWT (5.06) > MT (4.74). In detail, herdsmen in DT had a high LSI because they had high livelihood assets, livelihood strategies and disaster management capability. Herdsmen in MT had a low LSI, due to their low scores in terms of livelihood assets and livelihood strategies.

Table 7. Values of the livelihood sustainability index in Shenzha County.

Group	Livelihood Assets	Livelihood Strategies	Disaster Management Capability	Livelihood Sustainability Index
SWT	3.4870	0.6938	0.8832	5.0641
MT	3.3607	0.4833	0.8956	4.7396
DT	3.5931	0.7072	0.8960	5.1964

4. Discussion

The SLF is gaining attention for the purposes of addressing SL in a wide range of development organizations. The DFID framework introduces the main factors that influence livelihoods and relationships among them [8]. This framework contains a wide range of assets, considering not only traditional land resources, but also financial and social resources. Specifically, this framework highlights the importance of vulnerability contexts, and thus provides additional tools to assess impacts of vulnerability. The frequent occurrence of disasters and poverty in Shenzha make herdsmen communities highly susceptible to disaster vulnerability. What is worse, the frequent disasters have led to great loss to the production of agriculture and animal husbandry there. This is consistent with previous studies in which natural disasters have been established to have a great impact on the livelihoods of farmers and herdsmen [46–49].

From the perspective of the SLI constructed in our analysis, the results showed that (1) great disparity in the LSI can be observed among the three disaster groups. The scores of LSI for three groups were sorted in descending order as: DT > SWT > MT. In sum, herdsmen in DT and SWT had high LSI scores. Herdsmen have different livelihood assets under various disaster vulnerability contexts and thus have their own methods of collocation. (2) In detail, herdsmen in DT had a high LSI because they had high scores in terms of livelihood assets, livelihood strategies and disaster management capability. (3) Herdsmen in SWT had high scores in terms of livelihood assets, particularly human and financial assets, and livelihood strategies. However, herdsmen in SWT had low natural assets and social assets, and are thus forced to pursue other livelihood strategies. As a result, diversified livelihood strategies and high non-agricultural employment were observed. The diverse non-agricultural activities have not only increased the financial assets, but they have also promoted the SL of herdsmen in SWT. This is consistent with the findings of a previous study indicating that livelihood assets are complementary to obtaining SL [50].

(4) In comparison, herdsmen in MT had neither livelihood assets nor strategies, which restricted the SL of herdsmen there. In particular, herdsmen in MT had low physical assets and financial assets. It is difficult for herdsmen to use their existing livelihood assets to develop their livelihood strategies, which makes it difficult to enhance the SL of herdsmen. This elucidates some clues of the relationship between livelihood assets and strategies, even though this was not one of the aims of our paper. That is to say, under vulnerability contexts, livelihood strategies adopted by herdsmen depend on the status of the livelihood assets they own [51,52]. Herdsmen own one asset on the premise of acquiring another asset. In particular, human, financial and natural assets have significant positive impacts on farmers' livelihood strategies [39]. A diverse portfolio of livelihood activities is one of the key objectives of SL [53].

Complex disaster contexts in Tibet have been observed to cause great loss to SL [49]. The vulnerability of SL to disaster has been well-examined in previous studies, and great loss has been seen while coping with disasters [49,54]. Once disaster occurs, relief supplies from surrounding regions of the disaster area are costly. Adequate storage supplies for both human and livelihood are necessary conditions for a region to achieve SL. Moreover, the occurrence of disaster has a deep impact upon herdsmen and livestock. Thus, it is necessary to improve disaster management capabilities and increase storage supplies for the survival of humans and livestock in SWT. This is consistent with previous studies that demonstrate adaptions can improve livelihoods, and enhance the coping mechanisms of resilience from climatic shocks [20,55]. Failure of autonomous adaptation causes large economic consequences [56]. Placing the disaster management capability under analysis can help to further the understanding of SL.

5. Conclusions

The vulnerability contexts in Shenzha, Tibet are quite complex. Frequent climate disasters have greatly restricted normal productivity and influenced the SL of herdsmen. The vulnerability contexts of Shenzha are highlighted in our analysis. The LSI in our analysis was constructed based on livelihood assets and strategies, as well as disaster management capability, and the evaluation results reflect the practical conditions of the study area. According to the frequency of natural disasters, the towns in Shenzha were divided into three groups: SWT, MT and DT.

Moreover, our analysis provides guidance on how SL can be achieved in practice. It is noteworthy that diverse vulnerability contexts have various foundations of resource development, thus leading to disparity in the livelihoods of herdsmen. Based on the different disaster vulnerability contexts, strategies for improving SL should be considered differently. Furthermore, the third pole national park group is being constructed in Tibet, with the aim of achieving environment protection and sustainable development [57]. Therefore, by reducing dependence on grassland, the diverse strategies for herdsmen can not only led to an increase in the income of herdsmen, but also alleviate the vulnerability contexts. Moreover, with the construction of this national park, the development of tourism can promote diversified employment of herdsmen and contribute to SL, as has been well-confirmed in previous studies [58,59]. Therefore, this paper explored policy implications for the improvement of pre-disaster defense capability, disaster emergency relief and the reconstruction of post-disaster livelihood. In general, further strategies for dealing with SL should be employed for different types of disaster contexts. (1) For herdsmen in SWT, disaster management capability must be improved. Moreover, herdsmen in SWT have relevant non-agricultural experience, and thus could serve as employees for the national park. (2) Herdsmen in DT, who have been observed to own great natural assets, prefer to engage in husbandry activities. Therefore, in order to diversify their livelihood strategies, these herdsmen should be trained in non-agricultural skills. (3) For herdsmen in MT, active financial support should be adopted. Farmers with more financial assets tend to engage in diverse livelihood strategies and obtain more income.

Our analysis makes two contributions to the literature. The first is to remind researchers to take various vulnerability contexts into account when evaluating SL in disaster-prone areas. Little attention has been paid to the differentiation of SL caused by various vulnerability contexts. In this regard, our analysis offers empirical evidence for differentiating disasters, as they can result in various livelihood assets and strategies. The second contribution of our analysis is to present an LSI. The LSI raised in our analysis permits practical applications in other vulnerability cases. In sum, our analysis is of great significance, as it sheds new light on the comprehensive understanding of vulnerability contexts and disaster management capability. Moreover, it is noteworthy that SL encompasses the economic, social, and environmental aspects, which are also key hurdles to achieve the SDGs [60,61]. Among these, environmental systems are difficult to be separated, as they are usually interlinked [62]. In the context of the SDGs and climate changes, future studies on environmental components' effect on SL should be further explored.

Reference

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