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Quantifying Farm Household Resilience and the Implications of Livelihood Heterogeneity in the Semi-Arid Tropics of India

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Citation: Ramilan, T.; Kumar, S.; Haileslassie, A.; Craufurd, P.; Scrimgeour, F.; Kattarkandi, B.; Whitbread, A. Quantifying Farm Household Resilience and the Implications of Livelihood Heterogeneity in the Semi-Arid Tropics of India. *Agriculture* **2022**, *12*, 466. https://doi.org/10.3390/agriculture12040466

Academic Editor: Francesco Caracciolo

Received: 17 January 2022
Accepted: 14 March 2022
Published: 25 March 2022

Abstract: The vast majority of farmers in the drylands are resource-poor smallholders, whose livelihoods depend heavily on their farming systems. Therefore, increasing the resilience of these smallholders is vital for their prosperity. This study quantified household resilience and identified livelihoods and their influence on resilience in the semiarid tropics of India by analysing 684 households. A resilience capacity index was devised based on the composition of household food and non-food expenditure, cash savings, and food and feed reserves. The index ranged from 8.4 reflecting highly resilient households with access to irrigation characteristics, to −3.7 for households with highly limited resilience and low household assets. The livelihoods were identified through multivariate analysis on selected socioeconomic and biophysical variables; households were heterogeneous in their livelihoods. Irrigated livestock and rainfed marginal types had the highest and lowest resilience capacity index with the mean score of 0.69 and −1.07, respectively. Finally, we quantified the influence of livelihood strategies on household resilience. Household resilience was strengthened by the possession of livestock, crop diversification and access to irrigation. Low resilience is predominantly caused by low household assets. The resilience capacity index and derived livelihood strategies helps to understand the complexity of household resilience, and will aid in targeting technology interventions for development.

Keywords: resilience; livelihoods; household survey; crops; multivariate; semiarid

1. Introduction

The vast majority of households in the drylands of India depend on their farming systems for their livelihoods. Therefore, increasing the resilience of these smallholders is vital for their prosperity. A livelihood strategy can be defined as a portfolio of activities and choices that people make to achieve their livelihood goals [1]; therefore, understanding how various strategies contribute to resilience is important [2]. In the semiarid tropics of India, agricultural-based rural development is challenged by increasing population growth and the limited potential to increase productivity [3]. The research for the development (r4d) paradigm of the CGIAR centre, ICRISAT (International Crop Research Institute for Semi-Arid Tropics) focusses on improving the resilience of livelihoods using integrated system level interventions, which requires understanding of heterogeneity in livelihoods.

The concept of resilience varies depending on the context. The definition of resilience by Khan et al. [4] is related to the context of this paper as these authors have defined resilience in terms of adaptive capacity to respond to changes. Further, Khan et al. [4] have classified adaptive capacity in terms of socioeconomic, agricultural, and institutional capacity. Our focus here is on the contribution of household resilience towards overall wellbeing and hence, its ability to withstand shocks and how it varies with livelihood types. Livelihood heterogeneity in potential productivity and constraints must be embraced [5]. Livelihood typologies are key for developing targeted technologies and the scaling up of best fit options [6].

Therefore, our study explored the diversity in livelihoods. Most previous studies disaggregated livelihoods in a subjective fashion: i.e., via bottom up approaches, such as focus group discussions [6], or top down approaches, by defining livelihood types on the basis of expert knowledge or a single indicator such as size of the landholding or income shares from different sources, or according to the main income activity as stated by the household [7]. However, our study derives livelihood types through a robust data-driven approach with the use of multivariate analysis related to household resilience.

The objectives of the study are (i) to quantify resilience at the household level; (ii) to identify livelihood strategies and classify the households according to them; and (iii) to quantify the relative influence of livelihood strategies on resilience. The results of the study can be used to enhance resilience through appropriate policy and technological interventions. In pursuing these objectives, the remainder of the paper is organised as follows: Section 2 describes the study area and data; Section 3 describes the method of analysis; Section 4 presents the results; subsequently, Section 5 discusses the results and highlights the policy implications; and conclusions are drawn in Section 6.

2. Data and Study Area

Our analysis was based at the farm households. This is the primary decision-making unit, where the most important decisions on resource allocation are made [8]. Furthermore, farm households make important decisions regarding income generation, consumption, and coping with risk management. Households can therefore be considered as the most appropriate level for the analysis of resilience.

The data for this study were drawn from the Village Dynamics in South Asia (VDSA) Farm Household Survey conducted by ICRISAT [9]. This data has been widely used for household level research [10]. This data were collected by residential enumerators who visited the sample households approximately every 10 days over a three year period. We considered the data available for six VDSA villages located in three different regions: Aurepalle and Dokur in the Mahabubnagar region (Telangana), Kanzara and Kinkhed in the Akola region (Maharashtra), and Kalman and Shirapur in the Solapur region (Maharashtra) in India (Figure 1).

The locations of VDSA villages provides us with a great deal of heterogeneity in climate, weather, crop choice, and cultivation practices. The climate of this region is characterised by mean annual rainfall, ranging from 400 mm to 1200 mm with coefficients of variation ranging from 22 to 34 percent. The resilience of farm households is challenged by the increasing frequency and severity of droughts, characterised by a shift in the onset of the rains and the increasing occurrence of mid-season dry spells [2]. The predominant soils in the study area range from Alfisols of limited fertility and water-holding capacity, through to highly fertile Vertisols with large water-holding capacity.

Major crops cultivated are paddy rice, sorghum, wheat, maize, and cotton. These villages are representative of the broad agro-climatic conditions, soil variability, and cropping patterns within India's semiarid eco-regions [1]. Rainfall variability over the years is the major cause of yield uncertainty and makes rainfed agriculture one of the risky enterprises [11].

We pooled the latest generation VDSA data from 2009–2011. The effect of climatic variation and geophysical variables was minimised, with smoothing occurring as a result of the pooling of data across the locations and time [12].

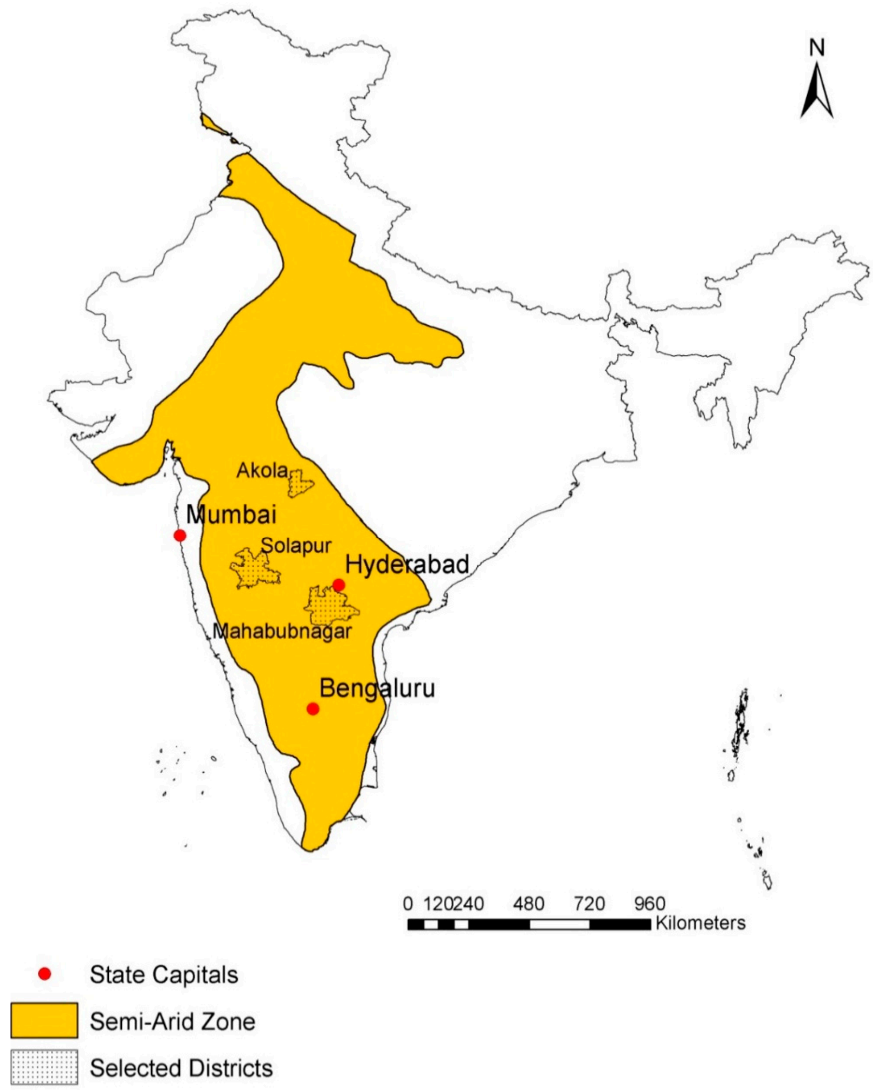

Figure 1. Study area. Since the data is a pooled cross section over three years, variables of monetary value were adjusted for inflation. This adjustment was conducted using India's consumer price index 2011 as the base year.

Initially, we carried out an exploratory data analysis to derive descriptive statistics for all potential variables through the resulting means, frequencies, and standard deviations. Given multi variate outliers artificially increase the variance, we eliminated such outlier observations from the sample using Mahalanobis' Distance, which accounts for the different scale and variance for each of the variables of a set in a probabilistic way (refer [13] for the details of algorithm). The distances among variables were calculated using the Moutlier function of the chemometrics package [14]. Observations beyond the 99th percentile cutoff point were eliminated. This resulted in 684 observations.

3. Method of Analysis

Principal Component Analysis (PCA), Multiple Ffactor Analysis (MFA), and Multiple Linear Regression were used in a sequence. These multivariate statistical methods have been widely used in farm system analysis to build farm typologies [15–20] and develop various indices such as food security, adaptive capacity, and vulnerability [5,21–23].

The analytical method applied consisted of four stages as described in Figure 2. In the first stage, we developed a multi-dimensional index named as the resilience capacity index (*RCI*) by identifying key variables and their associated weights through PCA. In the second stage, multifactor analysis was used to derive livelihood strategies. In stage three, households were classified into livelihoods based on their highest factor score. In stage four, we applied multiple linear regression on the resilience capacity index derived in stage one as a dependent variable against the livelihood strategies derived in stage two to explain their influence on household resilience. All calculations were performed using R programming language version 4.0.2 [24] supplemented by the additional Psych version 2.0.9 package [25].

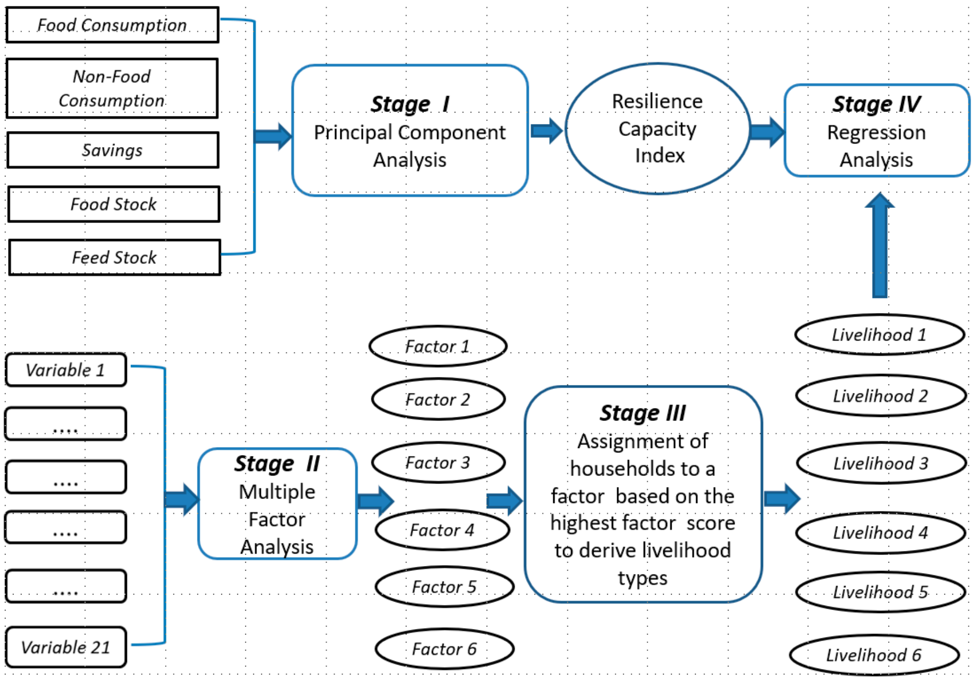

Figure 2. Overview of analytical framework.

3.1. Identifying Key Indicators for the Analysis

We identified key indicators for the analysis with the help of the literature as indicated in Table 1. Active family members per household includes the number of people in the age group 15–64 years. Mean education comprises education level of 16 years and above in the household. Drought-tolerant crops are *Macrotyloma uniflorum* (Horsegram), *Ricinus communis* (Castor), *Sorghum bicolor* (grain and fodder sorghum), *Cicer arietinum* (Chickpea), *Moringa oleifera* (Drumstick), *Pennisetum glaucum* (Pearl Millet), *Cyamopsis tetragonoloba* (Cluster Bean), *Vigna radiata* (Greengram), *Dolichos biflorus* (Hulga), *Vigna mungo* (Black gram), and *Cajanus cajan* (Pigeonpea) [26].

Livestock numbers are represented using tropical livestock units (TLU) from the International Livestock Research Institute as follows: cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chicken = 0.01. The soil fertility variable was derived by assigning numeric values to plot level data on farmer rating on soil fertility, namely: very good (4), good (3), poor (2), and very poor (1). The numeric soil fertility rating was multiplied by respective plot size to produce the soil fertility product. Theses fertility products were summed to generate area weighted fertility ratings for households. Non-land assets consists of farm equipment and durable goods such as automobiles and audio visual equipment.

Table 1. Identification of key indicators for the analysis.

Variables	Rationale for Choice
Active family members	An important for source for income generation [27,28].
Mean education	Less resilient households had a lower level of formal education [27,29].
Farm size and irrigated extent	Households with larger farm size and access to irrigation tend to be more resilient [30].
Crop diversity/Inter cropping/Drought-tolerant crops	Crop diversity increases the resilience [29,31].
Livestock	Livestock holding households are less exposed to drought [32,33].
Soil fertility	Key to the crop productivity [31].
Credit	Access to credit tend to have a positive and significant impact on household resilience [31].
Household income sources	Diversifying into agricultural and non-farm income generation increases resilience [34].

3.2. Generating an Index of Household Resilience Capacity

Our selection of resilience variables for *RCI* was guided by the literature focusing on resilience and vulnerability, mainly from [5,21,35]. The index is a latent variable defined by four continuous resilience indicator variables, namely: food consumption, non-food consumption, savings, and food and feed stock. A household's access to food depends on the availability of sufficient land and other productive resources to grow their own food [21] and the purchasing power generated from their farm and non-farm income activities. Food and non-food consumption are a proxy for their current level of wellbeing, while savings and food and feed stocks reflect their ability to sustain wellbeing into the future [5].

Food reserves help prevent disinvestment, depletion of assets, and enhance post shock recovery, thus contributing to household resilience [36]. Feed reserves aid in the maintenance of livestock health and productivity, thus preventing death or their under-valued sale during adverse climatic conditions. Another reason for including feed stock is the tradeoff between grain and fodder in some cropping enterprises, with cereals such as sorghum or maize. Furthermore, the reduced levels of non-food and food consumption expenditure are a proxy for vulnerability, when a household is hit by unexpected calamity [10]. These variables together represent resilience at the household level.

In algebraic terms, the resilience capacity index (*RCI*) of the *j*th household can be expressed as

$$RCI_j = f\left(FC_j, NFC_j, S_j, G_j, F_j\right) \tag{1}$$

where RCI_j = resilience capacity index, FC_j = food consumption expenditure, NFC_j = non-food consumption expenditure, S_j = cash savings, G_j = food stock, F_j = feed stock. *j* stands for households.

The identification of relative weights for each variable is a challenge [21]. Given its merit [21,37], we derived weights through the PCA. The PCA has been routinely used to generate indices; for instance, the World Food Program applied it to generate a food security and vulnerability index for households [38].

PCA was performed on the selected indicator variables chosen to reflect the resilience. PCA extracted a few orthogonal linear combinations of the variables (components). As suggested by [21,38,39], we used the loadings against each variable in the first component for weighting respective variables. Following this, we constructed the *RCI*, applying the formula below:

$$RCI_j = \sum \beta_i \left[\left(X_{ji} - X_i\right)/S_i\right)\right] \tag{2}$$

j denotes the household, *i* denotes variable. Where β_i loadings of the *i*th variable from the first principal component. X_{ji} is the *j*th household's value for the *i*th variable, and X_i and S_i are the mean and standard deviations of the *i*th variable for overall households. Based on the literature, we employed the OECD/EU standard conversion factor for developing countries, where female and child labour are converted into the adult male labour equivalents with respective conversion factors 0.8 and 0.3 [35]. *RCI* has a mean equal to zero and a standard deviation equal to one.

3.3. Identifying Livelihood Strategies

We used MFA to identify livelihood strategies among households. The technical details of MFA are described in [40]. A factor is a latent variable resulting from a composition of variables. Each household had a score for each factor. Further factors overcome the issue of multi co-linearity [40]. In stage three, each household was assigned to a livelihood strategy in terms of their highest factor score.

The mathematical model, p, denotes the number of variables ($X_1, X_2, \ldots, X_p$) and m denotes the number of underlying factors ($F_1, F_2, \ldots, F_m$). X_j is the variable represented in latent factors. Hence, this model assumes that there are m underlying factors whereby each observed variables is a linear function of these factors together with a residual variant. This model intends to reproduce the maximum correlations.

$$X_j = \propto_{j1} F_1 + \propto_{j2} F_2 + \ldots \propto_{jm} F_m \quad (3)$$

where $j = 1, 2, \ldots p$.

The factor scores are $\propto_{j1}, \propto_{j2}, \ldots, \propto_{jm}$, which denotes that $\propto_{j11}$ is the factor score of jth variable on the 1st factor. The factor loadings give us an idea about how much the variable has contributed to the factor; the higher the factor loading, the more the variable has contributed to that factor. The Kaiser–Meyer–Olkin (KMO) criterion was used to confirm the appropriateness of MFA on the selected variables [41]. The factors with eigen values greater than one were selected based on the Kaiser criterion. The selected factors were rotated using orthogonal rotation (Varimax method) for better interpretation [42]. Higher factor scores indicate a stronger contribution of the variable to the factor. According to [43], negative scores indicate those variables are negatively correlated with other variables in the same component.

3.4. Relative Influence of Livelihoods on Resilience

In stage four, the relative influence of the livelihood strategies on the *RCI* was assessed using multiple linear regression. Firstly, we checked whether the requirements of the Gauss–Markov theorem were fulfilled, i.e., that the expected value of the error term was zero, and the error term was homoscedastic and normally distributed. A direct regression analysis of the explanatory variables that have been derived based on the conceptual framework was not appropriate due to co-linearity problems. Regressors are factor scores of individual households for each livelihood.

4. Discussion

4.1. Resilience Capacity Index (RCI)

The first principal component represented 36 percent of the total variance. Descriptive statistics and loadings of indicator variables are presented in Table 2. *RCI* of the sample households ranged from −3.7 to 8.4 with a mean of 0.

Table 2. Means, standard deviations, and weights generated from PrincipalComponent Analysis (PCA).

Variables	Mean	Std	Weights
Food expenditure (USD per adult equivalent)	203	64	0.66
Non-food Expenditure (USD per adult equivalent)	229	220	0.49
Household savings (USD per household)	398	712	0.61
Food stock (USD per household)	86	75	0.67
Feed stock (USD per household)	29	48	0.54

The variation observed among the households in non-food expenditure was higher than in food expenditure. Household savings showed the highest variation. The weights generated from PCA reflected their relative importance in calculating *RCI*.

4.2. Identifying Livelihood Strategies

A total of 21 explanatory variables, which are significantly correlated with the *RCI*, were used for MFA and belong to different categories (Table 3). The value of KMO for the analysis is 0.81, which is regarded as meritorious and all KMO values for individual variables are equal or greater than 0.54, which is above the threshold limit of 0.50 [40]. This test indicates relatively compact patterns of correlations between the variables and hence justifying the use of MFA.

Table 3. Descriptive statistics of the parameters used for Multiple Factor Analysis (MFA).

Variables	Unit	Mean	Std.dev
Human capital			
Active family members	Numbers	3.6	1.4
Adult mean education	Years	5.4	3.2
Farm structure			
Farm size	Ha	3.6	2.9
Irrigated extent	% farm area	38	103
Drought-tolerant crops	% farm area	38	81
Inter cropping	% farm area	19	126
Legume crop	% farm area	36	102
Crop diversity	Number of crops/farm	4.9	3.0
Tropical livestock units	TLU	4.0	4.88
Soil fertility	Area weighted rating	7.4	5.5
Input use intensity			
Chemical fertilizer applied	kg per ha	200	198
Hired labour	hours per ha	558	433
Purchased feed	USD	44	102
Credit	USD	700	1659
Income			
Crop gross margin	USD per ha	276	592
Livestock gross margin	USD	187	1285
Non-farm income	USD	690	982
Market exposure			
Crop produce marketed	USD	602	1072
Livestock produce marketed	USD	175	374
Assets			
Value of farm equipment	USD per ha	113	306
Value of durable goods	USD	1575	1956
Land value	USD per ha	4254	4399

The factors derived through MFA represent the livelihood strategies. Each factor is characterised by the variables that have high loadings on them. We named livelihood strategies based on careful investigation of variable loadings after rotation (Figure 3). These strategies explained 54% of the variance. Given the number of observations, loadings of an absolute value of greater than 0.18 are considered significant [40]. Thus, all 21 variables contributed significantly to livelihood strategies. Loadings to the left of the central axis (dotted line) in each are negative; loadings to the right of the central axis are positive. All factors have variables with positive and negative loadings.

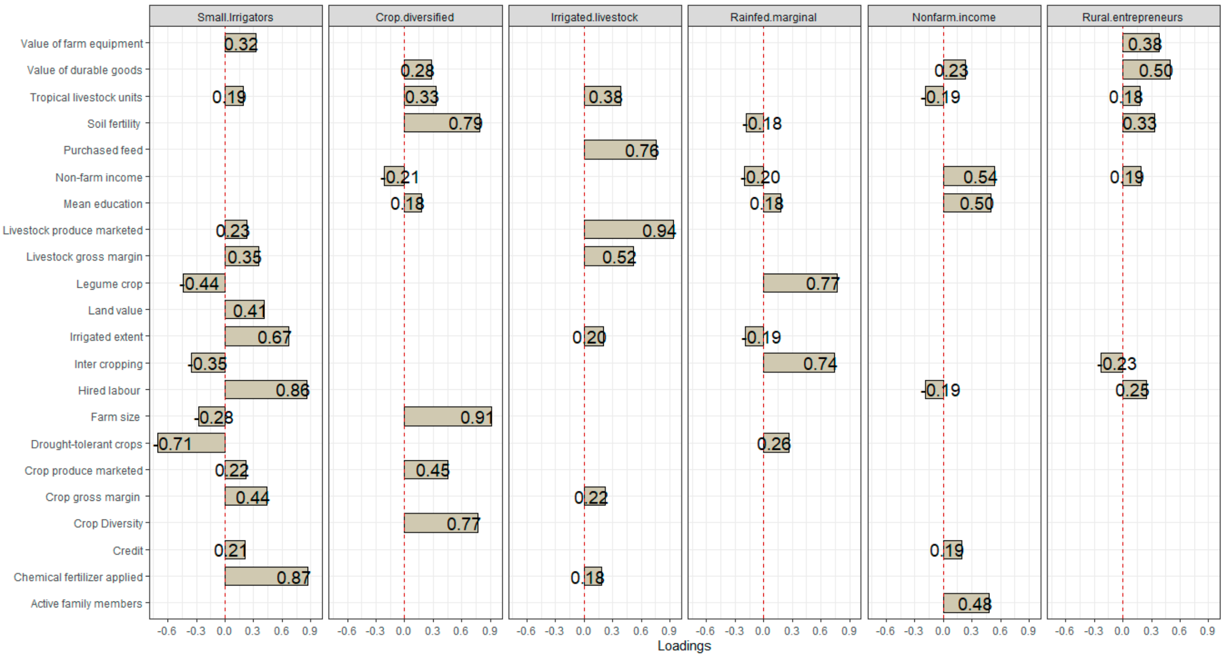

Figure 3. Variable loadings on six livelihood strategies resulted from MFA.

The first factor represents irrigated farm households with smaller land size and higher levels of fertiliser and labour use, land value, and negative loading on drought-tolerant crops indicate the lower level of such crops. The second factor represents crop-diversified livelihood, featuring larger farm size, marketing of produce, diversified cropping systems, and inter cropping. The third factor represents irrigated and livestock livelihood characterised higher loadings on TLU, purchased feed, livestock gross margin, and marketed share of livestock produce. The fourth livelihood strategy is rainfed marginal with higher levels of inter cropping. The fifth strategy involves non-farm income generated from skill-based activities such as salaried professional jobs and trades people. The sixth strategy is rural entrepreneurship, characterising rural entrepreneurs.

In the fourth stage, households were assigned to a particular livelihood strategy in terms of their highest absolute factor loading score (Table 4). Households belonging to small irrigators (A) are characterised by smaller farm sizes, a higher proportion (on average 65 percent) of land irrigated and are mainly producing for the market. They are intensive users of farm inputs such as hired labour, chemical fertiliser, and farm machinery, and devote most of their land and time to intensive cash cropping such as sugar cane and cotton. The livelihood of households in the crop-diversified type (B) has relatively large farm holdings. Their land use is characterised by a higher share in legumes of a drought-tolerant nature. Inter cropping is a predominant activity occupying 33 percent of land. Major inter cropping combinations are pigeon pea and ground nut; cotton and pigeon pea; and pigeon pea and rainy season sorghum. Households in irrigated and livestock livelihood type (C) are based on extensive livestock farming and access to irrigation. Average TLU is 7.2 and on average 52% percent of land is irrigated. Livestock are fed with a higher amount of purchased feed when compared to other livelihood types. Irrigated and livestock type is the most resilient category. Rainfed marginal (D) represents subsistence farmers who have the smallest land holdings with less or no irrigation and poor access to credit. Rain-fed marginal livelihood has significantly lower resilience when compared to all other livelihood types. Non-farm income households (E) have above-average education and active family members, which would enable them access to non-farm employment opportunities. Rural entrepreneurs (F) have the highest value of consumer durables and farm equipment per ha.

Table 4. Household characteristics by livelihood strategy (Mean).

Livelihood Strategy	Small Irrigators (A)	Crop Diversified (B)	Irrigated Livestock (C)	Rainfed Marginal (D)	Non-farm Income (E)	Rural Entrepreneurs (F)
RCI	0.11	0.62	0.69	−1.07	−0.06	0.29
Number of households	160	110	91	166	91	80
Active family members (numbers)	3.14	3.55	3.34	3.53	4.59	3.1
Mean education (years)	4.00	5.97	4.95	6.15	6.73	4.22
Farm size (ha)	1.6	3.3	2.1	1.1	1.5	2.2
Irrigated extent (ha)	1.3	1.7	1.6	0.3	0.8	0.9
Drought-tolerant crops (ha)	0.2	3	0.4	1.9	0.8	1.4
Inter cropping (ha)	0.1	2.5	0.3	1.7	0.4	0.2
Tropical livestock units	4.8	5.8	7.2	2.7	2.4	5.0
Soil fertility (rating)	6	14	8	4	6	9
Chemical fertilizer applied (kg/ha/year)	427	108	278	72	109	125
Hired labour (hours/ha)	1019	323	615	245	316	543
Purchased feed (USD)	43	32	240	5	26	17
Crop gross margin (USD/ha)	664	377	794	352	334	249

The means and standard deviations for the resilience capacity vary across livelihoods (Figure 4).

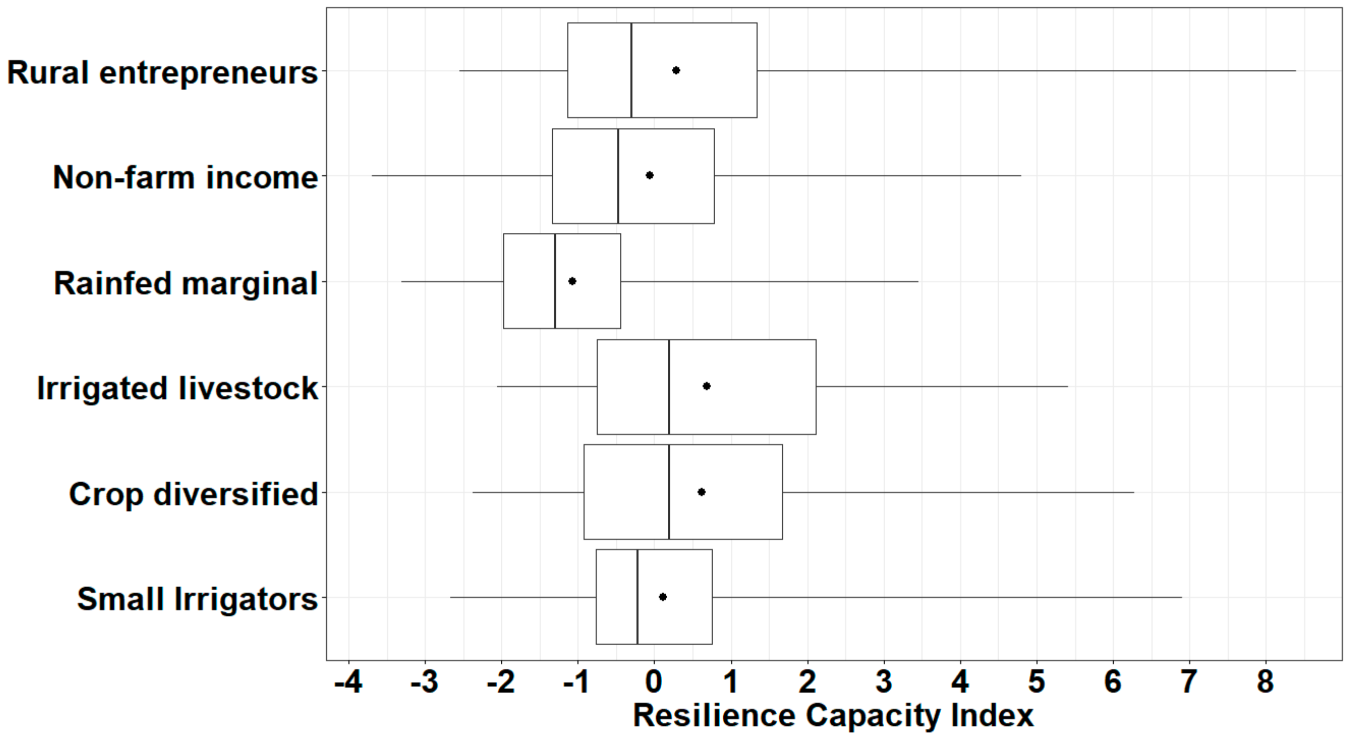

Figure 4. Comparison of resilience capacity across livelihood strategies (black dots indicate the mean and vertical lines indicate the median).

4.3. Influence of Livelihood Types on Resilience

Multiple pairwise comparison among livelihoods (Table 5) indicates the significance in differences among livelihoods' resilience capacity ranging from high significance to low with low *p* values.

Table 5. Mean differences between livelihoods.

Livelihoods	Estimate	Std. Error	t Value	Pr(>∣t∣)	
Non-farm income—Crop diversified	−0.67627	0.24773	−2.73	0.0696	.
Rainfed marginal—Crop diversified	−1.68709	0.20882	−8.079	<0.001	***
Non-farm income—Irrigated livestock	−0.74776	0.25839	−2.894	0.0444	*
Rainfed marginal—Irrigated livestock	−1.75857	0.22136	−7.944	<0.001	***
Small Irrigators—Irrigated livestock	−0.58186	0.2199	−2.646	0.0865	.
Rainfed marginal—Non-farm income	−1.01081	0.23085	−4.379	<0.001	***
Rural entrepreneurs—Rainfed marginal	1.35613	0.22136	6.126	<0.001	***
Small Irrigators—Rainfed marginal	1.17671	0.18678	6.3	<0.001	***

Significant levels: 0 '***' 0.001 '*' 0.05 '.' 0.1 ' ' 1.

The model has an R^2 value of 0.36 and, thus, explains 36% of the total variance in resilience capacity. The model was significant according to the F-test (F-statistic: 65.64) and associated *p* value ($<2.2 \times 10^{-16}$). The expected value of the error term was zero, and the error term was normally distributed. According to the Breusch–Pagan test value (28.2) and reported *p* value (8.767×10^{-05}), the error term is homoscedastic. The Durbin–Watson test results reveal that autocorrelation is lesser than 0 (DW = 1.6952, *p*-value = 2.122×10^{-16}). Further non-statistics of the RESET test with the value of 2.23 (*p* value 0.11) assures the appropriate model specification. All livelihood strategies contribute significantly towards resilience except for the rainfed marginal strategy (Table 6). The regression coefficients indicate that irrigated livestock, crop diversified, non-farm income, and rural entrepreneurs strongly influence farm household resilience followed by the small irrigators.

Table 6. Livelihood factors influencing farm household resilience.

Factors	Estimate	Stdard Error	t Value	Pr (>∣t∣)	Significance+
Irrigated livestock	3.24×10^{-16}	5.62×10^{-02}	5.756	1.30×10^{-08}	***
Crop diversified	6.65×10^{-01}	5.62×10^{-02}	11.821	$<2 \times 10^{-16}$	***
Small Irrigators	1.53×10^{-01}	5.81×10^{-02}	2.627	0.0088	**
Rainfed marginal	-4.35×10^{-01}	6.02×10^{-02}	−7.229	1.29×10^{-16}	***
Non-farm income	2.42×10^{-01}	6.97×10^{-02}	3.467	0.00056	***
Rural entrepreneurs	7.72×10^{-01}	7.06×10^{-02}	10.933	$<2 \times 10^{-16}$	***

Significance level: 0 '***' 0.001 '**'.

5. Discussion

Resilience capacity index varied across households. A higher resilience 10 apacity index implies greater resilience. The majority of households (59%) had an *RCI* below zero.

5.1. Influence of Household Parameters on Resilience Capacity Index

Small irrigator factor's higher loadings on crop gross margins can be attributed to higher yields and high value crops grown under irrigation, such as cotton. Promotion of irrigation is often cited as a strategy for enhancing income generation and food security for smallholder farmers [44]. Naturally, access to irrigation reduces the need to cultivate drought-tolerant crops. Negative loadings on land size indicates highly productive use of land enabled by higher soil fertility and input use. Fertiliser use per hectare of area has been reported to be the highest among small farm sizes and to decline with an increase in farm sizes [38]. Chand et al. [45] revealed that use of fertiliser per hectare by marginal farmers was on average 2.6 times higher than of large farmers. Access to irrigation reduces the need to cultivate drought-tolerant crops. Higher loadings on credit indicate their borrowing power enabled by the high value of land and cropping. Landholdings and other assets with collateral value play a vital role in having access to formal credit [46]. Credit presumably enables the intensive use of inputs.

In case of crop diversification, even though loadings on crop gross margins are not as significant as for the small irrigators, the crop diversification and higher volume production due to larger farm size leads to higher loadings on marketed crop produce. This reflects that farmers identify diversification as an effective strategy for managing business risk, particularly climatic risk. Using data from over 500 smallholder farmers, Makate et al. [47] demonstrated how crop diversification impacts on two outcomes of climate smart agriculture: increased productivity (legume and cereal crop productivity) and enhanced resilience (household income, food security, and nutrition) in rural Zimbabwe.

Rainfed marginal typifies the system with higher levels of inter cropping, drought-tolerant cropping, and a higher percent of legumes. Growing drought-tolerant varieties has been identified as the dominant important agronomic adaptation strategy [48]. The rainfed marginal livelihood has the lowest resilience capacity, which could be attributed to smaller landholding and non-availability of irrigation water. Lack of irrigation and smaller parcel size largely contributed to the low resilience in the rainfed marginal systems.

Non-farm system has high loadings on mean education and the active age of family members. Furthermore, this category has better access to credit, perhaps due to higher income-generating potential and owing to the high value of durables goods such as electronic goods, gold, and refrigerators. Stimulating poor households to follow market-oriented farm and non-farm activities can be carried out by improving access to education and vocational training for reducing poverty in the rural areas of central Nepal [49].

Rural entrepreneur's income is raised from leasing farm equipment, running small businesses (shops), and owning automobiles for provision of transport. Though the rural entrepreneurs have limited access to land and irrigation, a higher level of education enables these households to be more entrepreneurial and seek out alternative opportunities, in or out of agriculture.

One of the major differences between the crop-diversified system and rainfed marginal system is land size. Land size is positively related to household resilience. Hussain et al. [50] also found a positive relationship between farm size and ability to manage weather shocks. Since there is no idle land for expansion in most of the survey villages [51], households can expand only through buying or leasing the land (land consolidation). Therefore, smaller and non-resilient farms need to move out of agriculture to be absorbed in the non-agricultural sectors. In the literature [52], this is referred to as 'stepping out', whereby existing activities are used to accumulate assets for investment into a new venture.

A concerning feature is the low loading on institutional farm credit on all livelihoods, except small irrigators and non-farm income group. Credit can help in reducing poverty and improving livelihoods for the poor through offering the potential for them to engage in income-generating activities to meet household needs. Further access to credit promotes adoption of new technologies and enhances the risk-bearing ability of smallholder farmers [53]. However, the poor have often been kept outside the institutional credit line due to high transaction costs, a higher degree of default payments, and lack of collateral [54]. Sertse et al. [54] also reported challenges in acquiring credit, higher interest rates, and complicated loan procurement processes. This is especially true in villages of the semi-arid tropics [55]. There are links among different livelihood types, such as non-farm livelihoods link to farm-based livelihoods with markets for trading produce. Rural entrepreneurs' livelihood category plays a complementary role in input procurement and distribution, hiring out farm equipment such as tractors, seeder sprayers, and water pumps.

Livestock can act as a safety net for drought, since they can survive on natural pastures and communal lands, and tend to be less vulnerable to drought than crop production. According to [52], livestock keeping commonly has four important functions: providing for subsistence consumption (through home consumption of meat, milk, eggs, or fibre); supporting complementary (commonly cropping) activities (providing draught power and/or manure); buffering against seasonality in income from other activities (for example, cropping activities or seasonal labour); and providing some assets for insurance against unpredictable demands for cash. Further, livestock can be moved to other grazing areas or fed through purchased fodder and crop residues. Since diseconomies of scale may render crop production on very small farms that are unsustainable, keeping milking cows can be a better option [56] and provide a regular income source. Given the limitations in access to land and the low potential for crop production in rainfed marginal livelihoods, livestock production can be a complementary pathway to improve rural livelihoods. Income diversification into wage employment and rural entrepreneurship were found to have significant impact on resilience. Increasing share of non-farm activities for household income has been shown to improve household resilience [56].

Targeting technological interventions to livelihood diversity is important to reach the full potential of the intervention. Pannell et al. [57] emphasised the importance of considering heterogeneity in farming systems in promoting technology adoption. Identification of livelihood strategies is an efficient method to summarise the diversity of farming systems. This approach can be used to scale up the farm level in agricultural development research. Identified livelihoods are useful for building bioeconomic models to analyse the ex-ante impact of policies and new technologies [18].

5.2. Influence of Livelihood Types on Resilience

The explanatory power of the models is comparable to what was reported by [15] who studied the influence of socioeconomic household variables on climate adaptation ability. Nevertheless, the relatively large amount of unexplained variance indicates that a considerable number of predictors of resilience are missing from our model. However, this is difficult to avoid when studying highly multifactorial farming systems' resilience. Many factors can contribute to resilience, including institutions, property rights, and the completeness and effectiveness of markets. Rainfed marginal systems negatively contribute to the resilience. We envisage that building food stocks, encouraging household savings, and enhancing human capital via education and training are means of ensuring household resilience. The government and development partners should consider the heterogeneity in household livelihoods to enact better policy interventions. For example, on livelihood types such as rainfed marginal, research priority should be given to the development of more drought-resistant crop varieties, soil moisture conservation measures, and opportunities to diversify with livestock and fodder production, for example. Further, it has been reported that promising technologies and policy options for the management of drought risks as required for livelihood protection [36].

6. Conclusions, Implications for Policy and Future Research

The comprehensive measure of resilience at the household level is key for decision making. The variables used could be sourced through baseline surveys in planning any development initiatives. Further, this study provides clear understanding on the intricacies between resilient capacity resulting from household livelihoods.

The livelihoods identified in this study represented farm systems, which differ in their wealth, economic opportunities, and resource endowments. Identified livelihood types are a useful basis for future research to analyse the ex-ante impact of policies and new technologies. The livestock and irrigation contributed significantly to the resilience along with income diversification into wage employment and rural entrepreneurship. Irrigation and access to credit enabled higher amount of fertiliser use, which resulted in higher productivity and better market access. Policymakers can design policies that support farm-level adoption of risk management strategies, such as choice of crops, crop diversification, and access to irrigation and credit.

We found significant resilience capacity differences among households of different livelihoods and estimated the influence of livelihoods on resilience. We envisage that building food stocks, encouraging household savings, and enhancing human capital via education and training are means of ensuring household resilience. The government and development partners should consider the heterogeneity in household livelihoods to enact better policy interventions. We have not explicitly considered the spatial variability and adaptive capacity of farmers; however, the methods applied here can be extended to incorporate adaptation measures on resilience using high-resolution spatial data.

Author Contributions: Conceptualisation, T.R.; S.K.; A.H.; P.C.; F.S. and A.W.; investigation, T.R.; methodology, T.R.; S.K. and A.H.; data preparation, B.K.; statistical analysis, T.R.; writing—original draft, T.R.; writing—review and editing, T.R.; S.K.; A.H.; A.W.; P.C. and F.S. All authors have read and agreed to the published version of the manuscript.

Funding: Funding was received from the CGIAR Research Program's Dryland Systems (2013–2016) and Grain Legumes and Dryland Cereals (GLDC) (2017–2021) through various CGIAR fund donors is gratefully acknowledged.

Data Availability Statement: Data supporting reported results, available in a publicly accessible upon registering at the Village Dynamics in South Asia (VDSA) Knowledge Bank, (http://vdsakb.icrisat.ac.in/ accessed on 16 January 2022).

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

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