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Adaptive strategies enhance smallholders' livelihood resilience in Bihar, India

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Abstract
This study empirically assesses if and to what extent adaptive strategies contribute to smallholders' livelihood resilience in Bihar, India. The sustainable rural livelihoods framework has been implemented to understand how household livelihood systems may interact with the outside context. This poses significant empirical and methodological challenges, since studies of the interconnections between livelihood resources, livelihood strategies and livelihood outcomes from a quantitative point of view are still limited. The results extend the theoretical understanding of the relationships identified by the Sustainable Rural Livelihoods framework, and also provide empirical evidence about how livelihood resources, livelihood strategies and livelihood outcomes (food security in particular) are strictly interconnected. The study highlights that while the adaptive strategies implementation is influenced by the livelihood resources of rural households, it significantly influences the food security status of the smallholders in Bihar. On the basis of the above, the current study emphasizes the importance of targeted interventions to improve specific forms of households' livelihood resources which are prominent determinants of adoption of strategies that leads to the maintenance of resilience by environmentally dependent households in the developing world.

Keywords Sustainable rural livelihoods · Resilience · Adaptive strategies · Food security · India

1 Introduction

Agricultural systems are increasingly threatened by climatic stressors which can influence physiological processes and crop productivity, water use and soil properties, input prices and quantities sold at market (Knox et al. 2012). Sudden changes to the stream of income generated by farming activities may undermine the livelihood of the most vulnerable rural households (Caracciolo et al. 2014). This is a common problem in different parts of the world, but India in particular is one of the countries most exposed to climatic hazards (Maiti et al. 2015). Temperatures are projected to rise by 0.5 °C by 2030 (NIC 2009), while by 2050 rainfall is projected to increase in the autumn season and to decrease in the winter season (Lal et al. 2001; Prabhakar and Shaw 2008). Climate projections indicate more extreme weather events, such as floods and droughts. Such extreme events can stir up a sweeping decline in agricultural outputs, aggravating problems of rural poverty and food insecurity (Birthal et al. 2014). Moreover, due to its vast size and complex geography, India's climate has large spatial and temporal variations. This generates considerable uncertainty about when, where and how climate change will affect agricultural production in India (Lal 2011). Considering that about 68% of the Indian population (of over a billion people) is directly or indirectly involved in the agricultural sector, and a population increase of 19% is expected by 2050 (United Nations 2017), India faces a tough challenge. Indeed, the high dependence on the agricultural sector and the expected population growth combined with the unpredictable effects of weather vagaries could cause a serious food shortage in the near future (Ahmad et al. 2011).

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Among the Indian states, Bihar is characterized by a very large proportion of the population (almost nine out of every ten people) whose income is directly or indirectly tied to agricultural activities (Tesfaye et al. 2017). Furthermore, it is one of the most climate-sensitive states in India due to its hydro-meteorological fluctuations. Vagaries of rainfall, recurrent floods and droughts occurring in the same season in the same place are severely threatening the agricultural production of the state (Aryal et al. 2018) and, in turn, exacerbating the already limited food availability.

Given this scenario, a better understanding of how farming systems' resilience to the climatic stressors can be fostered is a matter of high priority in Bihar; there is still much uncertainty about which farming strategies are the most appropriate to mitigate these adverse impacts and what are the resources households need to develop to successfully implement such strategies.

The Sustainable Rural Livelihoods (SRL) framework provides a theoretical underpinning for identifying the ways through which livelihood outcomes, viz. resilience at household level, can be influenced by the strategies adopted. These in turn depend on the available household livelihood resources that are often grouped into human, social, natural, physical and financial capitals (Ellis 2000; Scoones 1998). Human capital improves the understanding of the risks associated with climate change and the importance of adopting appropriate management strategies; social capital makes it easier to manage contingencies; natural capital supports productive entrepreneurships; physical capital facilitates the adoption of livelihood strategies that improve resilience; financial capital makes it possible to develop adaptation measures and to accelerate recovery after shocks (Mutabazi et al. 2015).

The SRL framework has been long debated in the literature (FAO 2019; Butler and Mazur 2007; Randolph et al. 2007; Brock 1999). Numerous livelihoods approaches, perspectives, methods and frameworks currently exist and differ from each other to a considerable extent (De Haan 2000; Ellis 2000; Scoones 1998). Consequently, to date, there is no single, definitive conceptualization of the SRL framework (Small 2007). Furthermore, empirical studies seeking to demonstrate the link between livelihood resources, livelihood strategies and sustainable livelihood outcomes from a quantitative point of view are still limited to our knowledge. This may be due to the fact that these concepts are difficult to clearly characterise and, consequently, to quantify. Some studies adopt the framework only partially. For instance, the recent study of Asfaw et al. (2019) focuses the analysis exclusively on the impact of a diversification strategy on household welfare in Sub-Saharan Africa. Mutabazi et al. (2015) instead analyse a broader set of livelihood strategies that farmers have adopted in Tanzania to increase resilience to climate change and the linkages of such strategies to various indicators representing the livelihood resources (human, social, natural, physical and financial capitals). What is missing in the latter study is the important connection between the adoption of the livelihood strategies and the livelihood outcomes.

In light of this, this paper aims to contribute to this area of research with the specific objectives being (1) to empirically contextualize the SRL framework in a specific study site; (2) to identify rural farmers' level of adaptation to the undesirable climatic stresses in the study context; (3) to identify hidden correlations within the different adaptive strategies; and (4) to extend the theoretical understanding of the relationship between livelihood resources, livelihood strategies and livelihood outcomes from an empirical point of view.

In accordance with the first objective, the state of Bihar, India, is considered the study site for the present analysis due to its socio-economic and climatic conditions. Secondly, the composite index of resilience-building adaptive strategies (REBAS) developed by Mutabazi et al. (2015) is used to assess adaptation at the household level against changing climatic conditions. Thirdly and finally, this study conducts an empirical analysis to identify the linkages between the five capitals (viz. human, social, natural, physical and financial capitals), the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes (food security explicitly). The implications for food security have been explicitly assessed because Bihar is among the states of India with the highest prevalence of poverty and undernourishment (Kumar et al. 2016). The rest of the paper unfolds as follows: section two introduces the theoretical framework underlying this study; section three describes the study context; section four presents the methodological approach to the analysis; section five reports and discusses the main findings. The analysis ends with the conclusions and relevant policy implications.

2 The conceptual approach

Recognition that climate change could have negative consequences for agricultural production, and thereby for large percentages of the world's population that depends upon agriculture for their livelihoods, has stirred the necessity to build resilience into agricultural systems (Lin 2011). The concept of *resilience* pertains to the ability of a system to imbibe disturbances without changing its structure or function, and still preserving options to develop (Walker et al. 2002; Carpenter et al. 2001). In this context, *adaptive capacity* and *adaptation* are respectively the resources and strategies necessary to uphold the function of a system and to influence its state of resilience (Nelson 2011; Berkes et al. 2008; Eriksen and Kelly 2007; Füssel 2007; Tompkins and Adger 2005).

The current study has chosen to analyse these concepts of adaptive capacity, adaptation and resilience and the relationship between them by considering the Sustainable Rural Livelihoods (SRL) framework (Martin and Lorenzen 2016;

Niehof 2004; Bebbington 1999; Ellis 1999; Scoones 1998) as a theoretical basis for the current study (Fig. 1).

This framework recognizes households themselves as actors with a combination of assets (i.e. *adaptive capacity*) who implement specific strategies (namely *adaptation*) in order to pursue their own livelihood outcomes (viz. *resilience*). The asset base upon which households build their livelihoods is a portfolio of five different types of assets: human, social, natural, physical and financial capitals (Mayunga 2007; Scoones 1998). *Human capital* (e.g. knowledge and skills) refers to humans' capacity to understand risk and undertake adaptation strategies against climate change. *Social capital* (e.g. networks, social relations and associations) embraces the social connections and bonds that facilitate coordination and cooperation when pursuing different livelihood strategies. *Natural capital* (e.g. land and water) refers to the natural resource stocks and environmental services that provide capacity to sustain the livelihood strategies. *Physical capital* (e.g. infrastructures and technologies) includes material tools that will never be transformed into cash but help to increase agricultural productivity. Finally, *financial capital* (e.g. savings and credits) refers to the monetary resources to which a household has access.

Numerous studies have demonstrated that different endowments of the aforementioned capitals may explain a household's implementation of specific adaptation strategies against climatic stressors (García de Jalón et al. 2018; Wheeler et al. 2013; Below et al. 2012). Households will combine different assets to design specific strategies to achieve desirable "livelihood outcomes" (FAO 2019). Broadly, smallholders can adopt different strategies in response to climate stress, namely agricultural intensification, diversification, alteration and migration (Mutabazi et al. 2015). For instance, using physical and financial capital, smallholders may mitigate the possible fall in production by increasing the use of yield-enhancing agricultural inputs (Speranza 2013; Paavola 2008; David and Otsuka 1994). On the other side, a richer endowment of natural and human capitals may enhance the diversification of farming activities, by increasing the types or varieties of crops in the field (Bellon et al. 2016; Douxchamps et al. 2016; McCord et al. 2015; Lin 2011; Yachi and Loreau 1999), the integration of crops and livestock (Lemaire et al. 2014; Di Falco et al. 2011; Wilkins 2007; Russelle et al. 2007), the integration of trees into crop and/or livestock systems (i.e., agroforestry) (De Giusti et al. 2019; Hansen et al. 2019; Ajayi et al. 2009; Verchot et al. 2007) or via intercropping with legumes (Workayehu 2014; Rusinamhodzi et al. 2012). Previous research finds that households are likely to diversify income sources to increase livelihood security and improve farm efficiency (Bandyopadhyay and Skoufias 2015; Porter 2012; Ito and Kurosaki 2009; Mehta 2009; Menon 2009; Paavola 2008; Rose 2001; Kochar 1999). Another strategy to deal with the effects generated by climate change is based on the choice of crops to grow on-farm. Some farmers tend to introduce stress-resistant crop varieties that better suit the local conditions they face (Moniruzzaman 2015; Cho et al. 2014; Kurukulasuriya and Mendelsohn 2008). Among the various off-farm diversification strategies, the most widespread one focuses on the migration of one or more members of the household (Marchiori et al. 2012; Laczko and Aghazarm 2009; Ellis 2000). This is because migration for wage labour can produce remittances that lowers the liquidity constraint on non-migrating household members (Paavola 2008).

The above-mentioned adaptive strategies can help households manage and overcome negative effects generated by climate stressors (Yachi and Loreau 1999) and can be considered stand-alone measures or can be combined with each other. Some households may intensify, others diversify, while

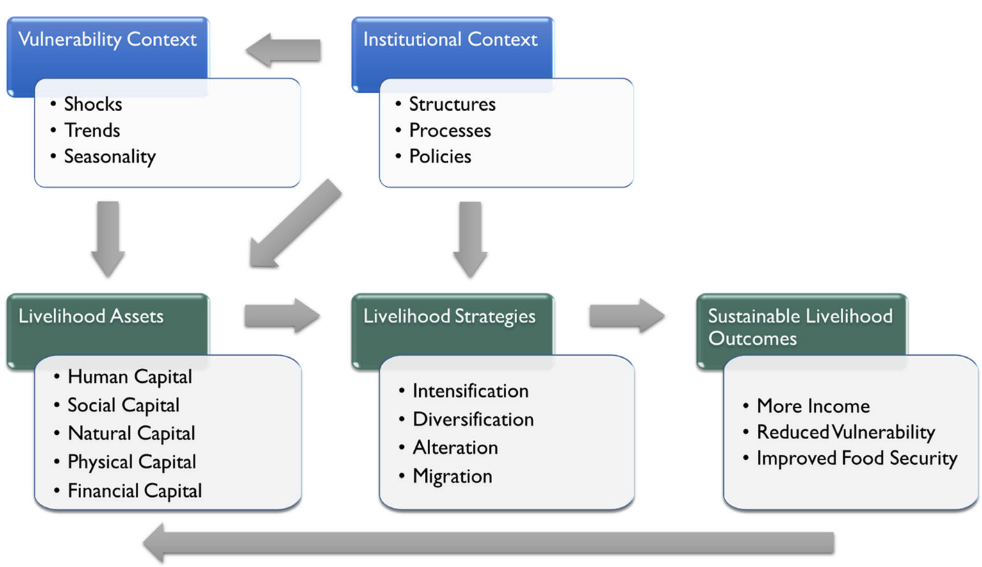


Fig. 1 The Sustainable Rural Livelihood Framework. Source: Adapted from Scoones (1998) and Carney et al. (1999)

there may be some who prefer to opt for migration, and households may also employ multiple livelihood strategies (Paavola 2008).

It is evident that livelihood outcomes can vary from one household to the next because they so heavily depend on multiple, multidirectional influences. Some studies consider conventional indicators such as crop yield, income, food consumption and sustainable use of natural resources as livelihood outcomes (Gotor et al. 2017; Bellon et al. 2015; Gotor et al. 2013). In other cases, a strengthened capital base, less vulnerability and improvements in other aspects of well-being such as health, self-esteem and even the maintenance of cultural assets are considered potential outcomes (Adato and Meinzen-Dick 2002). Moreover, livelihood outcomes are not necessarily the end point, as they can generate a feedback effect on the future state of vulnerability and base assets (Randolph et al. 2007).

Finally, it is important to highlight that the SRL framework embraces two sets of forces that are beyond the control of the household, but which influence households' livelihood outcomes: the vulnerability context and the institutional context. The concept of vulnerability refers to unpredictable shocks that can undermine households' livelihoods. It is not objective "risk" that matters, but households' subjective assessments of things that make them vulnerable. This is important because both perceived and actual vulnerability can impinge upon households' assets, and consequently their livelihood strategies (Adato and Meinzen-Dick 2002). The institutional context refers to outside policies, institutions and processes which influence access to assets and the vulnerability context, leading to the adoption of specific strategies to manage the negative impacts caused by extreme climatic events (ibid.).

The present paper is theoretically based upon this framework, while empirically it is contextualized in a specific study site: the State of Bihar, as illustrated in the next section.

3 Context of the study

The study was conducted in three districts of the State of Bihar: Saran, Vaishali, and Samastipur (Fig. 2). Bihar is located in north-east India in the plains of the Ganga river basin. It is the twelfth-largest state in India with an area of 94,163 sq. km (Majumder and Kumar 2019) and is endowed with fertile alluvial land and rich water resources, especially groundwater (Tesfaye et al. 2017).

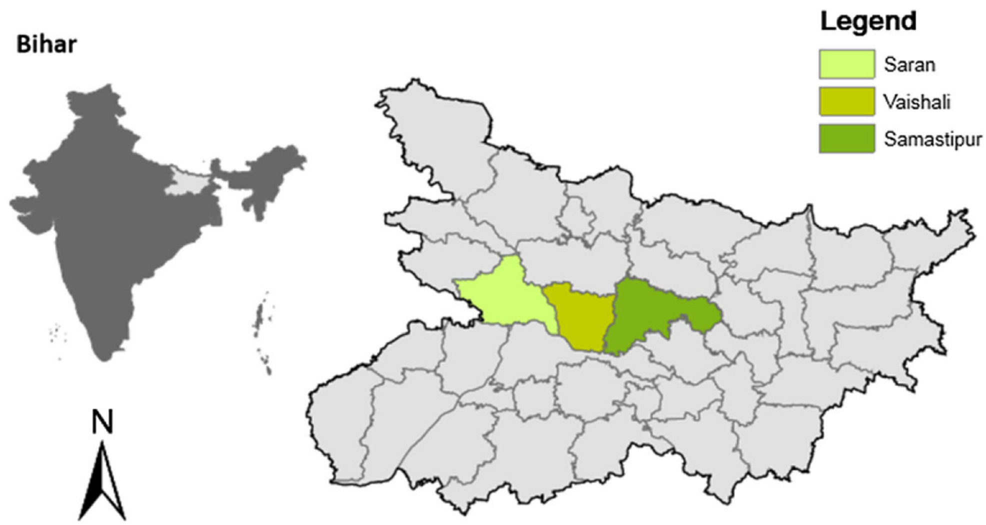
Nevertheless, Bihar has always faced significant obstacles to economic growth and development (Jha and Gundimeda 2019). According to Rasul and Sharma (2014), the state's poor economic performance over the years is due to high population numbers with poor skills, its weak agrarian structure, poor physical and economic infrastructures, issues of governance and institutional factors, an unequal distribution of resources and scarce foreign direct investments. Bihar's poverty ratio stands at 33.7% (Government of Bihar 2015) while the Human Development Index (HDI) is equal to 0.367 (Jha and Gundimeda 2019). According to the 2011 population census, Bihar is the third-most populous state in India, with almost 8.6% of the country's total population (Chandra et al. 2018) of which nine out of every ten people being rural residents (Jha and Gundimeda 2019). The literacy rate is equal to 61.8% which is below the national rate of 74%.

As previously stated, the economy of Bihar is largely dependent on agriculture. Indeed, agriculture contributes to one-fifth (21.3%) of Bihar's GDP and is the prime source of livelihood for about 90% of the population (Government of Bihar 2014). Several crops in different soil categories available in different agro-climatic zones are cultivated. For instance, Bihar is the sixth largest fruit producer in India (Kumar 2018), while rice, wheat, and maize are the major cereal crops. Rice is the main monsoon crop and is cultivated in all districts of Bihar. Wheat was increasingly planted by Bihari farmers after the Green Revolution and is currently the major crop of the winter season. Maize is also cultivated, with an average annual production level of approximately 1.5 million tons and a steady positive trend in production. Pulses such as mung bean, peas, and lentils are mostly grown in the southern parts of Bihar (Tesfaye et al. 2017; Government of Bihar 2014). However, 82% of landowners have less than one hectare of land (Kumar 2018) and the economic condition of farming communities is still miserable (Ahmad et al. 2017). Furthermore, average productivity for most of the crops, except maize and pulses, is well below the national average while population pressure is rising day by day (ibid.).

As for the exposure to the whims of an unpredictable climate, Bihar is definitely a disaster-prone state, especially concerning floods and droughts (Majumder and Kumar 2019). The high vulnerability of the state is due to the fact that Bihar forms a saucer-shaped valley located between the wet eastern coastal regions and the moderately dry continental region of the western plain (Jha and Gundimeda 2019). This means that regional variations in precipitation distribution and precipitation variability are much higher. Generally, the eastern and northern areas receive 2000 mm rainfall, whereas the western and south-western parts receive less than 1000 mm rainfall (Aryal et al. 2018). Consequently, southern Bihar is highly drought-prone, whereas northern Bihar is a highly flood-prone area (Government of Bihar 2012).

Recent studies project a general increase in monsoon rainfall and increases in both minimum and maximum temperatures across Bihar (Tesfaye et al. 2017; Kumar et al. 2006; Lal et al. 2001). The magnitudes of rainfall and temperature changes will vary depending on the site, indicating that the effect of climate change on crops will also vary by location (Tesfaye et al. 2017). This will be a major risk for crop production across Bihar. Particularly, changes in rainfall could

Fig. 2 Location of the study areas in Bihar, India



mostly affect autumn crops while the increase in temperature, particularly minimum temperatures, could be a major threat for winter- and spring-sown crops. Furthermore, an increase in rainfall amount and intensity would increase the chance of flash floods, flood conditions and lesser groundwater recharge, that in turn would also lead to an increase in atmospheric humidity, and in the duration of the wet season (Mall et al. 2006). Combined with higher temperatures, these conditions could favour the spread of fungal diseases, or the incidence of insect pests and vectors (Sharma et al. 2007). This is clearly detrimental to agricultural activities and food security, since small holdings of land are often not enough to keep households out of poverty even in optimal farming conditions (Chand et al. 2011).

Overall, Bihar presents a high exposure to climatic vagaries, and the myriad of social, economic, and institutional factors and their interplay shape the vulnerability of its people and the places they reside (Jha and Gundimeda 2019). Adaptation measures thus need to be designed and evaluated for the different farming systems of the state (Tesfaye et al. 2017).

4 Empirical analysis

4.1 Sample and data collection

Data were collected as part of the Seeds for Needs (S4N) India Impact Assessment study (Gotor et al. 2018a). The S4N program was supported by the Consultative Group on International Agricultural Research (CGIAR) with the purpose of promoting the use of the multiplicity of plant genetic resources as a means to decrease the vulnerability of rural households to climatic stress (Bioversity International 2018; van Etten et al. 2016). More specifically, Seeds for Needs addressed two main issues. First, the program addressed the scarce availability of stress-tolerant varieties by strengthening local seed systems. Seed varieties that were potentially adapted to local conditions and needs were firstly identified and then were distributed to farmers for participatory selection, implementing a "citizen scientist" approach (van Etten et al. 2019; Resnik et al. 2015; Dawson et al. 2008). Secondly, the program addressed the need to increase farmers' knowledge about sustainable production techniques through "Learning by Doing" trainings (Chandra et al. 2017).

A household questionnaire was administered between February and August 2018 in three districts of Bihar state: Saran, Vaishali, and Samastipur. The three districts have been identified through regional workshops conducted with national research institutes and grass roots organizations with strong ties to local farming communities. These workshops focused on identifying particularly vulnerable districts and villages, characterized by resource-poor farmers with small land holdings. The analysis is based upon 600 randomly selected rural households, which included 300 participants in the S4N program. Program participation was open to all community members and was voluntary - those who were interested participated. The 300 participating households included in this analysis were randomly drawn from this group, on the basis of the program records. The remaining households were randomly select from a list of all households within the same community (thus sharing similar environmental and institutional conditions as the participants) who had not explicitly participated in the program (150 households) and from similar and close villages (150 households), where the program was never implemented. The composition of the sample is illustrated in Table 1.

The household questionnaire was translated into local language (Hindi) for better understanding of enumerators and farmers. The data collection team consisted of three enumerators who attended a four-day training and field-testing series. One enumerator was designated team leader and was

Table 1 Sample composition

District	Village	Participants	Non-participants	Total Surveyed Households
Saran	**Bhagwanpur**	3	15	18
	Dharmagt Tola	0	19	19
	Khanpur	0	19	19
	Rampur Jaitti	18	21	39
	Sabalpur	8	13	21
	Sultanpur	10	24	34
Samastipur	Dhobgama	0	20	20
	Harpur	32	16	48
	Madapur	14	5	19
	Mahamada	36	12	48
	Narayanpur	0	17	17
Vaishali	**Bhathadasi**	57	28	85
	Fatehpur Chauthai	0	18	18
	Kariyo	10	3	13
	Kutubpur	0	23	23
	Mirpur Patadh	0	5	5
	Mukundpur	31	2	33
	Panapur	4	1	5
	Rajapakar	77	10	87
	Sembhopatti	0	20	20
	Vishanpura	0	9	9
Total		300	300	600

In bold are reported villages where the program was implemented

responsible for cross-checking all household data at the end of each day. The enumerators used electronic tablets to record the data using the Open Data Kit (ODK) platform. All data was uploaded to a server at the end of each day after being checked by the team leader. The household questionnaire used was adapted from the Rural Household Multi Indicator Survey (RHoMIS) (Hammond et al. 2017) following enumerators' feedback during the training. RHoMIS is a household survey tool designed to rapidly record a series of standardized indicators across the spectrum of agricultural production and market integration, nutrition, food security, poverty and greenhouse gas emissions. The questionnaire also collected standard socioeconomic information about household demographics, education, landholdings, sources of income, migration, and the gender-disaggregated allocation of decision-making power.

4.2 Definition of the SRL concepts

The first step of this study is the identification of specific variables to adequately represent the different concepts embodied by the SRL framework, namely *livelihood assets*, *livelihood strategies* and *sustainable livelihood outcomes*. As illustrated in Section 2, the interactions between the above-mentioned domains explain how rural households can adapt to a changing environment and build their livelihoods, but, from an empirical point of view, a concrete quantification of the SRL concepts is far from straightforward.

Livelihood assets include human, social, natural, physical and financial capital. The variables selected to quantify the different livelihood assets are the following:

i. *Human capital*: age and level of education of the household head, as well as the household size, are selected for human capital-related variables. Age of the household head can be considered as a proxy for farming experience (Patnaik et al. 2019; Deressa et al. 2009). Previous literature has identified both positive and negative relationships between the number of years of experience and the adoption of adaptive strategies (Maddison 2007; Shiferaw and Holden 1998). This study hypothesizes that age of the household head positively influences the use of various adaptation options. Highly experienced farmers are likely to have more information and knowledge about various management practices, and how to adjust them based on changes in environmental conditions and household needs. Similarly, a higher level of education facilitates access to information about agro-climatic aspects, so farmers with higher levels of education should adapt faster to climatic stressors (Below et al. 2012; Maddison 2007). Finally, the impact of household size on the adoption of adaptation measures can be seen from two perspectives. First, a large family size is usually associated with a higher labour force, which would allow a household to perform various agricultural activities. Second, large households may be forced to divert part of the workforce to non-agricultural activities in order to increase household income and alleviate the consumption pressure imposed by a large family (Deressa et al. 2009). Consequently, a positive relation is expected between the household size and the adoption of adaptation measures.

ii. *Social capital*: the level of trust and cooperation within the community is considered an indicator of social capital (Krishna 2004). High levels of trust and cooperation within the community are assumed to enable the adoption of adaptive strategies since social networks act as conduits for information and encourage people to engage in mutually beneficial efforts (Goodwin 2003). Female-headed households may have a lower ability to cope with climatic stressors since traditional social barriers may limit their access to information and other resources, in which case a negative relation is expected (Hassan and Nhemachena 2008; Tenge et al. 2004). Particularly in Bihar, women belonging to certain castes are forced to stay out of the labour market and remain confined to domestic duties (Government of Bihar 2020). Lastly, household participation in the S4N program was included as a variable to account for this source of social interaction. This is because the participation in program initiatives plays two distinct roles in the uptake of adaptive strategies. First, trainings were meant to raise farmers' awareness about sustainable production techniques and to build farmers' capacity for informed decision-making, all through hands-on experimentation and frequent interaction for knowledge and experience sharing. Second, the participatory approaches adopted by the program encourage the connection between and within communities and farmers, expanding the social capital of the rural households and enabling them to have access to alternative livelihood opportunities. Here it is expected that households who have participated in the development program are more likely to adapt to climate change.

iii. *Natural capital*: farm size easily represents the endowment of natural capital (Deressa et al. 2009). Since farm size is associated with greater wealth, it is expected that larger-scale farmers are likelier to undertake adaptive strategies than small-scale farmers would be (Aryal et al. 2014).

iv. *Physical capital*: the household appliance index has been calculated as the physical capital-related variable.[1] A home with a stove, refrigerator, television or motor vehicle denotes a certain level of well-being, which is a determinant of the likelihood that a household will adapt (Kuntashula et al. 2015). Moreover, a variable measuring whether a household has land ownership rights was measured, since it may influence investment decisions and households' resilience (Mutabazi et al. 2015). When farmers feel secure about land ownership, it is likelier they will investment in adaptation options. Indeed, ownership of land act as a positive incentive in facilitating farmers to make investments in their farms.

v. *Financial capital*: the financial capital-related variables measure whether a household has access to formal sources of credit (from the government, NGOs or other organisations) and/or informal sources of credit (from family, friends, or neighbours) (Patnaik et al. 2019; Bryan et al. 2013). Financial capital may positively influence the resilience capability since financial resources are crucial to implement various adaptation options (Bahinipati and Venkatachalam 2015). Whether a household has debts may adversely affect households' resilience capability (Taylor 2013).

The selected variables and their description can be found in Table 2.

4.3 Definition of the livelihood strategies

In order to identify which livelihood strategies households are adopting and to what extent, the resilience-building adaptive strategies (REBAS) index developed by Mutabazi et al. (2015) was implemented.

The first step in REBAS development is the selection of a set of variables related to the possible adaptive strategies (intensification, diversification, alteration and migration) that may contribute to the household's resilience. To compensate for a potential fall in yields, smallholders may choose a strategy of agricultural 'intensification' through the employment of yield-enhancing agricultural inputs (Speranza 2013; Paavola 2008). Consequently, in order to capture the presence of the intensification strategy, the number of different inputs (viz. fertilizer, manure, compost, pesticides and irrigation facilities) used for carrying out agricultural activities was counted.[2] Therefore, the variable considered to capture the implementation of an intensification strategy will range from 0 to 5. The diversification strategy included information on crop diversification (through the Simpson's Diversity Index) (Gotor et al. 2018b; Douxchamps et al. 2016; McCord et al. 2015), the use of intercropping with legumes by means of a dummy

[1] The predicted 1st factor from a Factor Analysis performed on assets such as a refrigerator, stove, pressure cooker, dressing table, electric fan, television, dining table or motor vehicle owned by a household was calculated.

[2] The selection of variables mostly followed literature based in African contexts due to the lack of specific studies in India. This could affect the interpretation of the absolute value of the score.

Table 2 Description of the livelihood assets and their expected influence on adaptation

Livelihood Assets	Expected influence	References
Human Capital		
Age of HH head (number)	+	Patnaik et al. 2019
Education of HH head (1 educated/0 no)	+	Maddison 2007
Household size	+	Deressa et al. 2009
Social Capital		
Gender of HH head (1 female/0 male)	–	García de Jalón et al. 2018
Trust & cooperation community	+	Goodwin 2003
Program participation (1 yes/0 no)	+	Wheeler et al. 2013
Natural Capital		
Farm size	+	Aryal et al. 2014
Physical Capital		
Land ownership right (1 yes/0 no)	+	Mutabazi et al. 2015
Appliance Index	+	Gotor et al. 2018b
Financial Capital		
Debts (1 yes/0 no)	–	Taylor 2013
Formal credit (1 yes/0 no)	+	Bryan et al. 2013
Informal credit (1 yes/0 no)	+	Bahinipati and Venkatachalam 2015

variable (Workayehu 2014; Rusinamhodzi et al. 2012), the presence of other forms of on-farm diversification (coexistence of livestock and/or agroforestry) (De Giusti et al. 2019; Wilkins 2007), as well as off-farm diversification (i.e. the amount of off-farm income sources). Concerning the alteration strategy, the use of early-maturing, drought-resistant or flood-resistant varieties and the early harvest of crops have been used (Moniruzzaman 2015; Cho et al. 2014; Kurukulasuriya and Mendelsohn 2008). That is, four different dummy variables related to the alteration strategy were considered. Finally, in the case of migration, the indicator used is a dummy variable that assumes a value of 1 if the household has access to remittances from migrated household members, 0 otherwise (Marchiori et al. 2012; Paavola 2008).

The next step is to create an objective weighting scheme that summarizes all the resilience-building adaptive strategies (intensification, diversification, alteration and migration) into a single composite indicator (the REBAS index). A principal component analysis (PCA) will then be carried out. Once the PCA is performed, the calculation of the REBAS index is computed as in Eqs. 1 and 2:

$$C_{jk} = \sum_{l} a_k^l \left(X_j^l \right) \tag{1}$$

$$REBAS_j = \sum_{k} v_k \left(C_{jk} \right) \tag{2}$$

where C_{jk} is k-th principal component for j-th household, a_k^l is the loading of k-th component for l-th variable and X_j^l are j-th household's values for i-th construct indicator. Moreover, $REBAS_j$ is the composite score of resilience-building livelihood strategies of j-th household and v_k is the variance accounted by the k-th principal component.

Finally, to obtain a standardized value, the REBAS was transformed into values ranging from 0 to 100 as follows in Eq. 3:

$$REBAS_j^s = \frac{H_i - H_{min}}{H_{max} - H_{min}} * 100 \tag{3}$$

$$j = 1, 2, 3, \ldots, \mathrm{N}$$

where $REBAS_j^s$ is the adjusted index of j-th household; H_i is the unadjusted index value for the i-th household in the sample, while H_{min} and H_{max} are respectively the minimum and the maximum value of the unadjusted index in the sample.

4.4 Definition of the livelihood outcomes

The current study aims to determine whether a linkage exists between the livelihood assets, the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes in Bihar, India. Here, food security is used as the main livelihood outcome. Ensuring the food security of its citizens has been one of the key developmental aspirations of India (Sajjad and Nasreen 2014). Nevertheless, Bihar is one of the states with the highest levels of food insecurity (Swaminathan 2001). Food security is directly and indirectly related to climate change. Climatic stressors affect food security by influencing the availability and accessibility of food, steadiness of food supplies and instability in food prices (Birthal et al. 2014). Obviously, the impacts of climatic stressors on households' food security are unforeseeable as they depend on the type and extent of the shock and the characteristics of the reference context (Vermeulen et al. 2012; Hertel and Rosch 2010).

To determine the relation between the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes, the Household Food Insecurity Access Scale (HFIAS[3]) was employed in this analysis (Coates et al. 2007). The HFIAS is a set of nine questions that covers a recall period of 30 days[4] and captures households' behavioural and psychological manifestations of insecure food access. Each of the nine questions is scored 0–3, with 3 indicating the highest frequency of occurrence. At the end, the scores for all questions are added together. The total HFIAS can range from 0 to 27 allowing the household to be pinpointed on a spectrum that indicates a higher degree of food insecurity with a higher score.

4.5 Econometric model

Once the different concepts embodied by the SRL framework (livelihood assets, livelihood strategies and sustainable livelihood outcomes) have been properly identified and quantified, the following step consists of analysing the relationships and interactions between the above-mentioned domains to explain how rural households may adapt to a changing environment and build their livelihoods in terms of food security. In a nutshell, the study aims to understand the relationship between livelihood assets, livelihood strategies and livelihood outcomes theorized by the SRL framework.

From an empirical point of view, a Tobit model with endogenous regressors (Eq. 4–5) was implemented to address censored data and endogeneity.[5] More specifically, the two-step procedure suggested by Newey (1987) has been followed for the parameters' estimation. In the specific case analysed, the identification of the causal effect of REBAS on the HFIAS (as hypothesised in the SRL framework) may suffer from some endogeneity bias, as the food security (HFIAS) may directly or indirectly influence the household adoption of livelihood strategies (REBAS) as well.

$$HFIAS_j^* = Rebas_j\beta + z_{1j}\delta + \varepsilon_j \tag{4}$$

$$REBAS_j = z_{1j}\pi_1 + z_{2j}\pi_2 + u_j \tag{5}$$

Wherein, for each j-th households, $REBAS_j$ is the endogenous variable; z_{1j} is a $1 \times k_1$ vector of exogenous variables, with δ the relative parameter $1 \times k_1$ vector; z_{2j} is a $1 \times k_2$ vector of additional instruments. By assumption $(u_i, \varepsilon_i) \sim N(0)$. β is the parameter measuring the effect of REBAS on HFIAS, and π_1 and π_2 are matrices of reduced-form parameters.

Within the SRL framework, the variables representing the exogenous change of the vulnerability and institutional contexts are reasonable candidates to address endogeneity, affecting the adaptation level of rural households (REBAS), without having any direct impact on the livelihood outcome (HFIAS). Therefore, this study employs two variables as instruments: whether households were exposed to climatic stressors and a dummy variable identifying the villages where the development program was implemented. The validity of the instruments has been tested through the Sargan test of over-identifying restrictions.

5 Results and discussion

5.1 SRL construct

As previously illustrated, the initial part of the study identifies and quantifies the different concepts embodied by the SRL framework, namely livelihood assets, livelihood strategies and livelihood outcomes. The descriptive statistics of the variables employed in the analysis are presented in Table 3. Among the livelihood assets, the table shows that the average age of the household heads of the sample is around 47 years with only 24% of them as female. The average household size in the surveyed area is 7.57 people, with a minimum of 2 members and a maximum of 20 members. One- tenth of respondents have a household size of 2–4 members, which is considered as a small family – typically the husband, wife and two children. A large proportion of the households (62%) are medium sized in terms of number of members, while only 10% of the households in the sample are extended households with more than 12 members Regarding the farms, 96% of the households claim to own the land they cultivate. The average size of a farm is 1.50 acres, which is in line with the state average. Land holdings in Bihar consist predominately of marginal (0–2.5 acres) and small (2.5–5 acres) farm holdings with a high degree of fragmentation (Government of Bihar 2015). Almost 60% of the sample finds it difficult to repay debts, while just a small percentage of people sampled have

[3] The HFIAS was developed between 2001 and 2006 by the USAID-funded Food and Nutrition Technical Assistance II project (FANTA) in collaboration with Tufts and Cornell Universities, among other partners.

[4] Applications of food insecurity scales can use recall periods ranging from 12 months to 24 h. The choice of recall period should be based on different considerations. A long recall period could generate recall bias, that is, underestimation of food quantities because of memory failure. A short recall period could generate telescoping errors, that is, the quantities consumed are overestimated (Smith et al. 2006). Furthermore, too short recall periods tend to be time consuming and may not capture the complex notion of food security (Maxwell et al. 2008). The 30-day recall period could represent the right period of time to analyse the degree of food insecurity of households.

[5] All the estimations have been carried out using STATA version 16.

Table 3 Description of the Sustainable Rural Livelihood constructs and descriptive statistics of the variables employed in the analysis

SRL Construct	Variable	Mean	Std. Dev.	Min	Max
Human Capital	Age of household head (number)	47.39	12.50	16	90
Human Capital	Education of household head (1 educated/0 no)	0.68	0.47	0	1
Human Capital	Household Size (number)	7.57	3.08	2	20
Social Capital	Gender of household head (1 female/0 male)	0.24	0.43	0	1
Social Capital	Trust & cooperation community (level)	2.24	0.72	0	4
Social Capital	Project participation (1 yes/0 no)	0.50	0.50	0	1
Natural Capital	Farm size (acres)	1.50	1.58	0.16	18
Physical Capital	Land ownership right (1 yes/0 no)	0.96	0.19	0	1
Physical Capital	Appliance Index	66.04	29.76	0	100
Financial Capital	Debts (1 yes/0 no)	0.59	0.49	0	1
Financial Capital	Formal credit (1 yes/0 no)	0.05	0.22	0	1
Financial Capital	Informal credit (1 yes/0 no)	0.03	0.18	0	1
Intensification Strategy	Agricultural inputs (count)	4.83	0.52	0	5
Diversification Strategy	Simpson's Diversity Index	0.21	0.26	0	1
Diversification Strategy	Intercropping with legumes (1 yes/0 no)	0.41	0.49	0	1
Diversification Strategy	Diversification on-farm (n. activities)	0.80	0.45	0	2
Diversification Strategy	Diversification off-farm (n. activities)	0.76	0.53	0	2
Alteration Strategy	Harvest early (1 yes/0 no)	0.79	0.41	0	1
Alteration Strategy	Early-maturing varieties (1 yes/0 no)	0.79	0.41	0	1
Alteration Strategy	Drought-resistant varieties (1 yes/0 no)	0.71	0.45	0	1
Alteration Strategy	Flood-resistant varieties (1 yes/0 no)	0.50	0.50	0	1
Migration Strategy	Remittances (1 yes/0 no)	0.22	0.41	0	1
Adaptive Strategies	REBAS Index	51.68	23.55	0	100
Outcome	HFIAS	1.46	2.02	0	27

access to formal or informal sources of credit (5% and 3% respectively). Credit is an important input to accelerate agricultural production and productivity. Indeed, the demand for financial resources for cropping, inputs and other machinery have been increasing in Bihar. However, the State does not have an adequate financial structure capable of meeting this demand (Government of Bihar 2020).

Focusing on the livelihood strategies, the variable related to the intensification strategy presents a mean value of 4.83, indicating that farmers employ almost all the agricultural inputs considered (viz. fertilizer, manure, compost, pesticides and irrigation facilities). Due to the small size of people's landholdings, and the general lack of off-farm opportunities in rural areas, smallholders are largely forced to follow intensification strategies to generate enough income (Chand et al. 2011). Conversely, the Simpson's Diversity Index is equal to 0.21. This is evidence that a strategy based on the diversification of cultivated crops is not widespread among the rural households considered in the analysis. Indeed, all the sampled households tend to focus their agricultural production on rice and wheat. These results are in line with the state trend of rice and wheat together representing over 70% of the total gross cropped area of Bihar (Government of Bihar 2020). Others crops cultivated by the households in the sample are potatoes (83.50%), maize (56.50%), mustard (41.83%), pulses (13.83%) and chili (8.50%). Moreover, the dummy variables associated with the alteration strategy present a mean value above 0.70, except for the adoption of flood-resistant varieties that has a mean value of 0.50. Lastly, one-fifth (22%) of the sample received remittances from migrant household members. The combination of natural, economic, and social factors in Bihar push household members to migrate (Jha et al. 2018). At the same time, remittances help in the overall improvement of well-being for migrant households in Bihar. Tumbe (2011) found that the dependence on domestic remittances is much higher in Bihar than the average for India.

The bottom of the table provides values for the livelihood outcome considered by this study. As can be seen, the HFIAS is equal to 1.46 which indicates that the observed households have a high level of food security. Overall, half of the households in the sample have total access to food (HFIAS = 0). These findings are in line with the study by Bhatta et al. (2013) in which slightly more than 50% of the households sampled in Bihar were food secure throughout the year.

5.2 Identification of the livelihood strategies

Once the empirical construct of the SRL framework was established, the next step concerned the calculation of the resilience-building adaptive strategies (REBAS) index, reflecting the portfolio of adaptive strategies adopted by the farm households and their correlations. The computation of such an index is based on an objective weighting scheme derived from the PCA of the dataset.[6] Table 4 illustrates that the first component of the PCA is based on all the alteration practices, i.e. the adoption of drought- and flood-resistant varieties, early-maturing varieties and the adjustment of harvesting dates according to weather conditions. Migration (receiving remittances) and a subset of diversification strategies (namely carrying out off-farm activities) have highest loadings in the second component. Two different practices of an on-farm diversification strategy (the integration of livestock and/or agroforestry and intercropping with legumes) have maximum loading in the third component. The last component shows a high correlation between the identified intensification measure (viz. amount of inputs used in the agriculture activity) and a subset of diversification strategies (namely crop diversification).

These results illustrate the internal correlations among the different classes of adaptive strategies identified in the study (intensification, diversification, alteration and migration). The diversification strategies observed within the sample population are comprised of on-farm diversification and intercropping with legumes. Intercropping with legumes is an appealing option to address climate risk for farm households, because it can reduce the risk of crop failure and improve productivity (Workayehu 2014; Rusinamhodzi et al. 2012). On-farm diversification activities include the integration of crops and agroforestry and/or livestock. Tree-based systems are able to maintain production during wetter and drier periods and to mitigate climate change through enhanced carbon sequestration (Verchot et al. 2007). Raising livestock in mixed crop-livestock systems is a common practice in India, as a substantial share of animals' energy requirements comes from crop by-products and residues (Birthal et al. 2014). Furthermore, local integration of cropping with livestock systems would allow greater flexibility of the whole system to cope with potential socio-economic and climate change induced threats and improve the quality of grasslands through periodic renovations (Lemaire et al. 2014; Di Falco et al. 2011; Wilkins 2007; Russelle et al. 2007). Households tend to combine different diversification strategies within a portfolio as a sort of "insurance" against unpredictable, future stressors. The fact that on-farm diversification and intercropping with legumes present a high positive correlation indicates that Indian farmers tend to adopt a portfolio of strategies that reduce the risk of crop failure while providing an alternative source of income if the crop failure actually occurs. This is in line with the study by Beillouin et al. (2019) which shows that a combination of different diversification strategies can generate better results than the adoption of a single strategy. The second and fourth components of the PCA instead highlight that some strategies are considered by Indian farmers as alternative strategies. Not surprisingly, diversification beyond on-farm activities and migration are negatively correlated, as is the intensification strategy and the strategy based on interspecies diversification. Only the alteration strategy is adopted by rural households as a stand-alone measure. The PCA does not reveal hidden correlations with other adaptive strategies. Considering that Bihar is a state particularly sensitive to climatic whims, especially droughts and floods, it is intuitive that farmers tend to introduce stress-resistant crop varieties that better suit the local conditions they face and also adjust harvesting dates according to weather conditions.

5.3 SRL relationships

The final part of the study analyses the relationships between livelihood resources, livelihood strategies and livelihood outcomes as indicated by the SRL framework. To assess this objective, a Tobit model with endogenous variables was implemented. Results of this part of the study can be found in Table 5.[7] The results of the first stage of the model bring out a number of insights about the linkages between the livelihood assets and the identified strategies. Social capital-related variables have a significant positive effect on the resilience-building measure. This is in accordance with previous studies (Mutabazi et al. 2015; Isham 2002). High levels of trust and cooperation within the community have been shown to reduce social barriers that may hamper the employment of adaptation strategies (Groenewald and Bulte 2013). Interestingly, the model shows that female-headed households are more likely to take up climate change adaptation methods. This could be related to the fact that women are deeply engaged in agricultural work and therefore have greater experience and access to information about management and farming practices (Nhemachena and Hassan 2007). This result is interesting since in Bihar women tend to be excluded from all forms of economic activity, including those within their own farms, due to socio-cultural restrictions (Government of Bihar 2020). However, in the rare cases that women are indeed the

[6] Varimax rotation has been performed to minimize the number of variables that have high loading on one component. Statistical tests such as Bartlett's sphericity test and the Kaiser–Meyer–Olkin measure indicate that the PCA is appropriate.

[7] The Sargan test showed exogeneity of instruments. Moreover, results from the test for weak instruments indicates that the selected instruments were relevant.

Table 4 PCA components used for resilience-building adaptive strategies (REBAS) index construction

Resilience-building strategy	Indicators	Components*			
		1	2	3	4
Intensification	Agricultural inputs	−0.0549	−0.0479	−0.0219	**0.8320**
Diversification	Crop diversification (SDI)	−0.3009	−0.1327	−0.1159	**−0.4694**
Diversification	Intercropping with legumes	−0.0070	−0.0905	**0.7297**	−0.0006
Diversification	Diversification on-farm	−0.0154	0.3706	**0.4302**	0.0589
Diversification	Diversification off-farm	0.1137	**0.6824**	0.0363	−0.1279
Alteration	Harvest early	**0.4248**	−0.1324	−0.2430	0.1430
Alteration	Early-maturing varieties	**0.4150**	0.0470	−0.2088	−0.1589
Alteration	Drought-resistant varieties	**0.4795**	−0.1165	−0.0283	−0.0466
Alteration	Flood-resistant varieties	**0.5252**	0.1555	0.2102	−0.0540
Migration	Remittances	0.1866	**−0.5581**	0.3458	−0.1296
Percentage of variance explained		0.25	0.17	0.13	0.12
Cumulative variance percentage		0.25	0.41	0.54	0.67

*Bold figures highlight the highest component loading

head of the household, they seem to be conducting the role effectively, especially regarding the management of their farms. Likewise, participation in the S4N program is associated with a higher level of adaptation. From this it is possible to assert that the program was able to provide the information and tools needed to stimulate the implementation of appropriate strategies to adapt to climate stressors.

On the other hand, natural capital has a negative and significant influence on the level of adaptation of Indian farmers. This result can be associated with the high land fragmentation that characterizes Bihar. The fragmentation of land for cultivation can represent a limiting factor in the adoption of adaptation measures. Among the physical capital variables, whether households have land ownership rights does not appear to significantly affect adoption, while the appliance index has a significantly negative effect on rural adaptation levels. This could be explained by substitution in adaptation options (García de Jalón et al. 2018), where some wealthier rural households may prefer coping strategies over adaptation strategies. In case of financial capital, access to formal sources of credit positively and significantly influences the REBAS index. It can be inferred that receiving financial aid from the government, NGOs or other organizations loosens liquidity constraints and stimulates households' adaptation to climatic stressors. Conversely, the coefficient of the debts variable is negative and significant. As expected, farmers who find it difficult to repay their debts are less likely to adopt adaptation measures against climate stress.

Despite evidence from various sources suggesting human capital is an important determinant of adoption of farm-level adaptation measures (García de Jalón et al. 2018; Below et al. 2012; Hassan and Nhemachena 2008; Deressa et al. 2009; Maddison 2007), this study's results did not suggest that this capital positively affects the adaptation of rural Indian households. Probably this result can be associated with the choice of the variables implemented in this study to describe and quantify human capital, since data availability did partially constrain the selection of variables.

Results of the second stage of the Tobit model highlight the negative and significant influence of the REBAS index on the HFIAS. This means that high levels of adaptation to the negative effects of climate vagaries are associated with positive levels of food security of rural Indian households. The result is in line with previous research suggesting that the adoption of adaptive measures improve the food security status of households (Douxchamps et al. 2016). It represents a noteworthy result because much of Bihar's population depends on agriculture, a famously climate-sensitive sector. Extreme climatic events can cause a drastic decline in agricultural outputs, exacerbating problems of food insecurity and rural poverty. The food insecurity assessment founded on the dimension of food access reflects the demand side of food security and is widely used (Salarkia et al. 2014). The household's access to food depends on its own food production and the food it can acquire through sale of the agricultural products it produces, or the allocation of its workforce to other economic activities. If climatic vagaries reduce agricultural production, the resources available to households to meet their food needs are almost automatically reduced. Furthermore, is not always possible to increase the resilience of agricultural systems even if adaptive measures are adopted (Nelson 2011). In some cases, adaptation can undermine resilience. In light of this, the results of the current analysis are relevant as they provide empirical evidence that Bihari farmers with higher levels of adaptation are able to reduce the negative effects of climatic vagaries on access to food, to a certain extent.

Table 5 Results of the Tobit regression with endogenous variables

Variables	Regression results			
	Coef.	SE	*z*	
REBAS Index				
Age of household head	−0.010	0.363	−0.03	
Squared age of household head	0.000	0.004	−0.08	
Education of household head	−0.702	2.003	−0.35	
Household Size	0.249	0.274	0.91	
Gender of household head	8.067	2.156	3.74	***
Trust & cooperation community	13.895	1.150	12.08	***
Program participation	6.487	1.995	3.25	***
Farm size (ln)	−3.900	1.097	−3.55	***
Land ownership right	−5.188	4.305	−1.20	
Appliance Index	−0.084	0.028	−3.01	***
Debts	−3.806	1.586	−2.40	**
Formal credit	12.862	3.535	3.64	***
Informal credit	−4.160	4.422	−0.94	
Exposure to climatic stressors	2.385	5.128	0.47	
Village project implemented	−4.490	2.329	−1.93	*
Constant	28.627	11.004	2.60	***
HFIAS				
REBAS Index	−0.475	0.247	−1.92	*
Age of household head	0.402	0.173	2.32	**
Squared age of household head	−0.004	0.002	−2.45	**
Education of household head	−0.982	0.953	−1.03	
Household Size	0.221	0.142	1.55	
Gender of household head	1.873	2.112	0.89	
Trust & cooperation community	4.653	3.575	1.30	
Program participation	2.146	1.338	1.60	
Farm size (ln)	−1.622	1.071	−1.51	
Land ownership right	−3.176	2.647	−1.20	
Appliance Index	−0.040	0.023	−1.72	*
Debts	−0.767	1.234	−0.62	
Formal credit	2.661	3.542	0.75	
Informal credit	−1.830	2.344	−0.78	
Constant	8.135	8.672	0.94	

$n = 600$; Level of significance: * 10%; ** 5%; *** 1%;

R^2 (REBAS eq.) = 38.32; Wald χ^2 (HFIAS eq.) = 57.41 (p value <0.001); Wald test of Exogeneity χ^2 = 7.69 (p value = 0.006); Sargan test of overidentifying restriction χ^2 = 1.45 (p value = 0.228)

Finally, among the capital-related variables, the empirical analysis suggests that the appliance index directly influences the level of food security of rural households in the study site. This in alignment with the study by Mbukwa (2014) that shows that physical capital is positively associated with food security. Furthermore, the age of the head of household positively affects HFIAS, while age squared negatively affects HFIAS. Empirical results indicate that households with older heads tend to be food secure and households with younger heads tend not to be. The result is consistent with previous studies (Zhou et al. 2019).

6 Conclusion

This study empirically contextualized the SRL framework in Bihar, one of the most climate-sensitive states in India wherein widespread floods and droughts threatened the agricultural production of the state (Aryal et al. 2018) undermining the livelihood of its extremely dense and poor rural population (Tesfaye et al. 2017). The identification of main SRL concepts first allowed to understand in which way household livelihood resources and strategies are interconnected and may impact livelihood outcomes, such as food security.

The first objective of the analysis was to identify adaptation strategies adopted in the study site's agricultural systems. Results showed that only the alteration strategy is adopted by Indian farmers as stand-alone measure. The other identified strategies are considered as alternative measures, such as diversification beyond on-farm activities and migration or intensification and crop diversification. Only a subgroup of diversification strategies (i.e. intercropping with legumes and other practices of on-farm diversification) is perceived as complementary measures.

Lastly, the study aimed to further understand the relationships traced by the SRL framework. To examine the interplay of capitals, strategies, and outcome, a Tobit model with endogenous variables was implemented. The results of the empirical model bring quantitative evidence on how livelihood resources (human, social, natural, physical and financial capitals), livelihood strategies (proxied by the REBAS index) and livelihood outcomes (food security) are linked. The results of the first stage of the model emphasise that adaptation of the farming system is influenced by the livelihood resources of rural households, in particular with regard to social, natural, physical and financial capitals. The results of the second stage indicate that adaptation of the farming system is positively linked with the food security status of the farm households. This result demonstrates that by introducing some adaptation strategies, the negative effect of climatic vagaries on access to food can be minimized to some extent. This is not a foregone conclusion, however, because is not always possible to increase the resilience of agricultural systems even if adaptive measures are adopted (Nelson 2011).

Interestingly, the empirical analysis shows that human capital has no significant influence on households' choice of livelihood strategies, but it can directly impact the level of food security of rural Indian households. Physical capital is negatively associated with adaptation level, but it positively influences rural households' food security level. Such results suggest remarkable considerations: (1) not all livelihood assets are associated to adoption of livelihood strategies; (2) the influence of some livelihood assets on the livelihood outcomes could be conveyed by the adoption of specific livelihood strategies, while in other cases (3) some livelihood assets could be directly linked to livelihood outcomes.

The current study thus emphasizes the importance of targeted interventions to improve specific forms of households' livelihood resources, being key determinants for adaptation strategy adoption in the face of climate stressors. In particular, interventions need to focus on promoting women empowerment and dismantling barriers to social integration among community members and between different communities. Especially, in areas like Bihar (and India in general) that are characterized by pronounced gender gap and fragmented social capital. Given the overall responsibility for food security ascribed to women and girls within rural households, food security approaches must pay attention to the elimination of gender inequality and promote women's empowerment, as they are important preconditions for food security. Social networks can promote cooperation and facilitate access to information about best farming management practices and climate change. At the same time, policy interventions should create the financial environment that allows farmers to adapt to climate change and to access the food needed to meet the household's dietary requirements. In recent years, the demand for financial resources for farm investments have been increasing in Bihar (Government of Bihar 2020). Improved financial capital would make households more resistant to stresses as it promotes greater accessibility and availability of resources. Financial stability of the poor in rural areas, especially women, is crucial for overall empowerment of these households. All this is pivotal to guarantee a linear process for environmentally dependent households in the developing world to maintain and improve resilience.

The results of this analysis do not offer a one-size-fits-all solution. As illustrated above, different rural households adopt different livelihood strategies because adaptation occurs across broad spatial and temporal scales. Consequently, farmers could adopt different adaptive strategies in other parts of the world, or they could switch their livelihood strategies as climate and demographic conditions evolve. Furthermore, different measures of livelihood assets are appropriate for different social and cultural contexts. A constrained variable selection due to limited data, the extensive reference to African contexts rather than Indian contexts, and the absence of key climate parameters like temperature and rainfall in the analysis can be considered to be limitations of the current analysis. Nevertheless, our empirical quantification and validation of the SRL framework may represent a valid operating procedure to better understand dynamics between livelihood assets, livelihood strategies and livelihood outcomes in other contexts.

Further research could improve the methodological approach of the current analysis by including more predictors of adaptation, such as variables that describe farmers' perceptions and attitudes toward climatic risks, or by extending the range of livelihood outcomes that could be pursued by the households, such as yield stability or the sustainable use of natural resources.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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