

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.

26 **1. Introduction**

27

28 Agricultural systems are increasingly threatened by climatic stressors which can influence
29 physiological processes and crop productivity, water use and soil properties, input prices and
30 quantities sold at market (Knox et al. 2012). Sudden changes to the stream of income generated by
31 farming activities may undermine the livelihood of the most vulnerable rural households (Caracciolo
32 et al. 2014). This is a common problem in different parts of the world, but India in particular is one
33 of the countries most exposed to climatic hazards (Maiti et al. 2015). Temperatures are projected to
34 rise by 0.5 °C by 2030 (NIC 2009), while by 2050 rainfall is projected to increase in the autumn
35 season and to decrease in the winter season (Lal et al. 2001; Prabhakar and Shaw 2008). Climate
36 projections indicate more extreme weather events, such as floods and droughts. Such extreme events
37 can stir up a sweeping decline in agricultural outputs, aggravating problems of rural poverty and food
38 insecurity (Birthal et al. 2014). Moreover, due to its vast size and complex geography, India's climate
39 has large spatial and temporal variations. This generates considerable uncertainty about when, where
40 and how climate change will affect agricultural production in India (Lal 2011). Considering that about
41 68% of the Indian population (of over a billion people) is directly or indirectly involved in the
42 agricultural sector, and a population increase of 19% is expected by 2050 (United Nations 2017),
43 India faces a tough challenge. Indeed, the high dependence on the agricultural sector and the expected
44 population growth combined with the unpredictable effects of weather vagaries could cause a serious
45 food shortage in the near future (Ahmad et al. 2011).

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

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

56 The Sustainable Rural Livelihoods (SRL) framework provides a theoretical underpinning for
57 identifying the ways through which livelihood outcomes, viz. resilience at household level, can be

58 influenced by the strategies adopted. These in turn depend on the available household livelihood
59 resources that are often grouped into human, social, natural, physical and financial capitals (Ellis
60 2000; Scoones 1998). Human capital improves the understanding of the risks associated with climate
61 change and the importance of adopting appropriate management strategies; social capital makes it
62 easier to manage contingencies; natural capital supports productive entrepreneurs; physical
63 capital facilitates the adoption of livelihood strategies that improve resilience; financial capital makes
64 it possible to develop adaptation measures and to accelerate recovery after shocks (Mutabazi et al.
65 2015).

66 The SRL framework has been long debated in the literature (FAO 2019; Butler and Mazur 2007;
67 Randolph et al. 2007; Brock 1999). Numerous livelihoods approaches, perspectives, methods and
68 frameworks currently exist and differ from each other to a considerable extent (De Haan 2000; Ellis
69 2000; Scoones 1998). Consequently, to date, there is no single, definitive conceptualization of the
70 SRL framework (Small 2007). Furthermore, empirical studies seeking to demonstrate the link
71 between livelihood resources, livelihood strategies and sustainable livelihood outcomes from a
72 quantitative point of view are still limited to our knowledge. This may be due to the fact that these
73 concepts are difficult to clearly characterise and, consequently, to quantify. Some studies adopt the
74 framework only partially. For instance, the recent study of Asfaw et al. (2019) focuses the analysis
75 exclusively on the impact of a diversification strategy on household welfare in Sub-Saharan Africa.
76 Mutabazi et al. (2015) instead analyse a broader set of livelihood strategies that farmers have adopted
77 in Tanzania to increase resilience to climate change and the linkages of such strategies to various
78 indicators representing the livelihood resources (human, social, natural, physical and financial
79 capitals). What is missing in the latter study is the important connection between the adoption of the
80 livelihood strategies and the livelihood outcomes.

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

87 In accordance with the first objective, the state of Bihar, India, is considered the study site for the
88 present analysis due to its socio-economic and climatic conditions. Secondly, the composite index of
89 resilience-building adaptive strategies (REBAS) developed by Mutabazi et al. (2015) is used to assess
90 adaptation at the household level against changing climatic conditions. Thirdly and finally, this study

91 conducts an empirical analysis to identify the linkages between the five capitals (viz. human, social,
92 natural, physical and financial capitals), the livelihood strategies (proxied by the REBAS index) and
93 the livelihood outcomes (food security explicitly). The implications for food security have been
94 explicitly assessed because Bihar is among the states of India with the highest prevalence of poverty
95 and undernourishment (Kumar et al. 2016). The rest of the paper unfolds as follows: section two
96 introduces the theoretical framework underlying this study; section three describes the study context;
97 section four presents the methodological approach to the analysis; section five reports and discusses
98 the main findings. The analysis ends with the conclusions and relevant policy implications.

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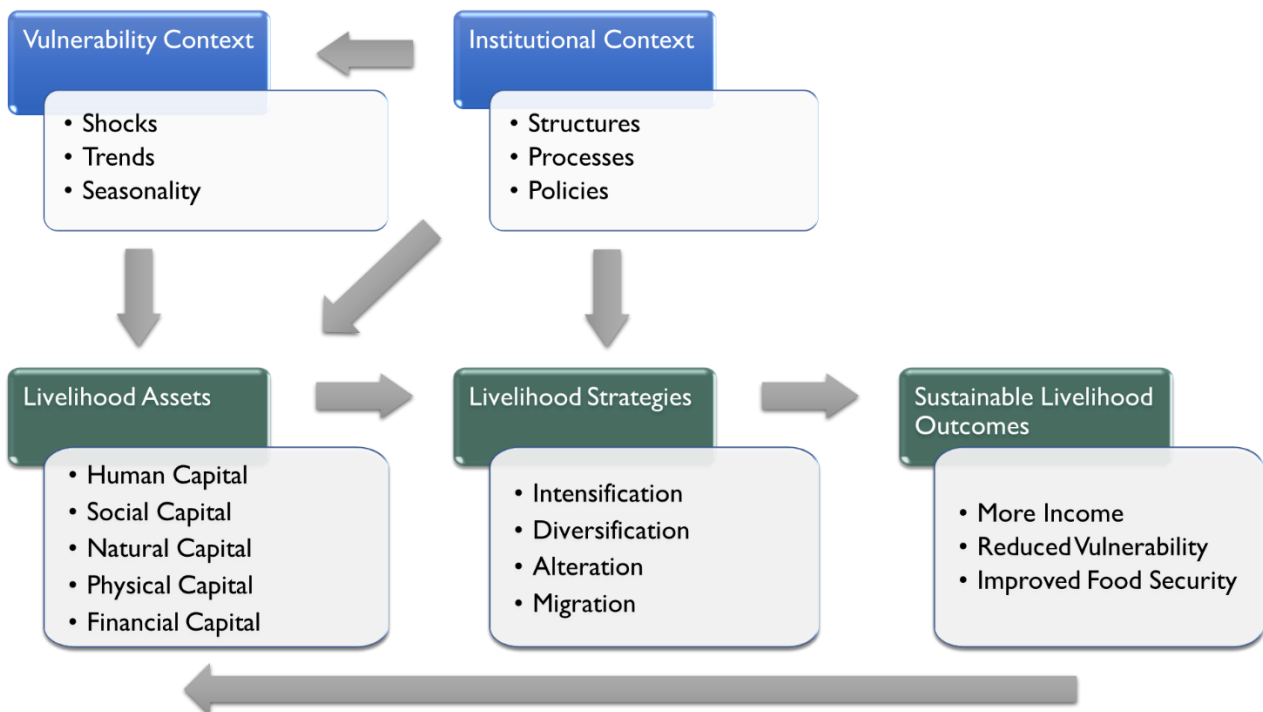
100 **2. The Conceptual Approach**

101

102 Recognition that climate change could have negative consequences for agricultural production, and
103 thereby for large percentages of the world’s population that depends upon agriculture for their
104 livelihoods, has stirred the necessity to build resilience into agricultural systems (Lin 2011). The
105 concept of resilience pertains to the ability of a system to imbibe disturbances without changing its
106 structure or function, and still preserving options to develop (Walker et al. 2002; Carpenter et al.
107 2001). In this context, adaptive capacity and adaptation are respectively the resources and strategies
108 necessary to uphold the function of a system and to influence its state of resilience (Nelson 2011;
109 Berkes et al. 2008; Eriksen and Kelly 2007; Füssel 2007; Tompkins and Adger 2005).

110 The current study has chosen to analyse these concepts of adaptive capacity, adaptation and resilience
111 and the relationship between them by considering the Sustainable Rural Livelihoods (SRL)
112 framework (Martin and Lorenzen 2016; Niehof 2004; Bebbington 1999; Ellis 1999; Scoones 1998)
113 as a theoretical basis for the current study (Fig. 1).

114 **Figure 1.** The Sustainable Rural Livelihood Framework



115

116 Source: Adapted from Scoones (1998) and Carney et al. (1999).

117 This framework recognizes households themselves as actors with a combination of assets (i.e.
118 adaptive capacity) who implement specific strategies (namely adaptation) in order to pursue their own

119 livelihood outcomes (viz. resilience). The asset base upon which households build their livelihoods
120 is a portfolio of five different types of assets: human, social, natural, physical and financial capitals
121 (Mayunga 2007; Scoones 1998). Human capital (e.g. knowledge and skills) refers to humans’
122 capacity to understand risk and undertake adaptation strategies against climate change. Social capital
123 (e.g. networks, social relations and associations) embraces the social connections and bonds that
124 facilitate coordination and cooperation when pursuing different livelihood strategies. Natural capital
125 (e.g. land and water) refers to the natural resource stocks and environmental services that provide
126 capacity to sustain the livelihood strategies. Physical capital (e.g. infrastructures and technologies)
127 includes material tools that will never be transformed into cash but help to increase agricultural
128 productivity. Finally, financial capital (e.g. savings and credits) refers to the monetary resources to
129 which a household has access.

130 Numerous studies have demonstrated that different endowments of the aforementioned capitals may
131 explain a household’s implementation of specific adaptation strategies against climatic stressors
132 (García de Jalón et al. 2018; Wheeler et al. 2013; Below et al. 2012). Households will combine
133 different assets to design specific strategies to achieve desirable “livelihood outcomes” (FAO 2019).
134 Broadly, smallholders can adopt different strategies in response to climate stress, namely agricultural
135 intensification, diversification, alteration and migration (Mutabazi et al. 2015). For instance, using
136 physical and financial capital, smallholders may mitigate the possible fall in production by increasing
137 the use of yield-enhancing agricultural inputs (Speranza 2013; Paavola 2008; David and Otsuka
138 1994). On the other side, a richer endowment of natural and human capitals may enhance the
139 diversification of farming activities, by increasing the types or varieties of crops in the field (Bellon
140 et al. 2016; Douxchamps et al. 2016; McCord et al. 2015; Lin 2011; Yachi and Loreau 1999), the
141 integration of crops and livestock (Lemaire et al. 2014; Di Falco et al. 2011; Wilkins 2007; Russelle
142 et al. 2007), the integration of trees into crop and/or livestock systems (i.e., agroforestry) (De Giusti
143 et al. 2019; Hansen et al. 2019; Ajayi et al. 2009; Verchot et al. 2007) or via intercropping with
144 legumes (Workayehu 2014; Rusinamhodzi et al. 2012). Previous research finds that households are
145 likely to diversify income sources to increase livelihood security and improve farm efficiency
146 (Bandyopadhyay and Skoufias 2015; Porter 2012; Ito and Kurosaki 2009; Mehta 2009; Menon 2009;
147 Paavola 2008; Rose 2001; Kochar 1999). Another strategy to deal with the effects generated by
148 climate change is based on the choice of crops to grow on-farm. Some farmers tend to introduce
149 stress-resistant crop varieties that better suit the local conditions they face (Moniruzzaman 2015; Cho
150 et al. 2014; Kurukulasuriya and Mendelsohn 2008). Among the various off-farm diversification
151 strategies, the most widespread one focuses on the migration of one or more members of the
152 household (Marchiori et al. 2012; Laczko and Aghazarm 2009; Ellis 2000). This is because migration

153 for wage labour can produce remittances that lowers the liquidity constraint on non-migrating
154 household members (Paavola 2008).

155 The above-mentioned adaptive strategies can help households manage and overcome negative effects
156 generated by climate stressors (Yachi and Loreau 1999) and can be considered stand-alone measures
157 or can be combined with each other. Some households may intensify, others diversify, while there
158 may be some who prefer to opt for migration, and households may also employ multiple livelihood
159 strategies (Paavola 2008).

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

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

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

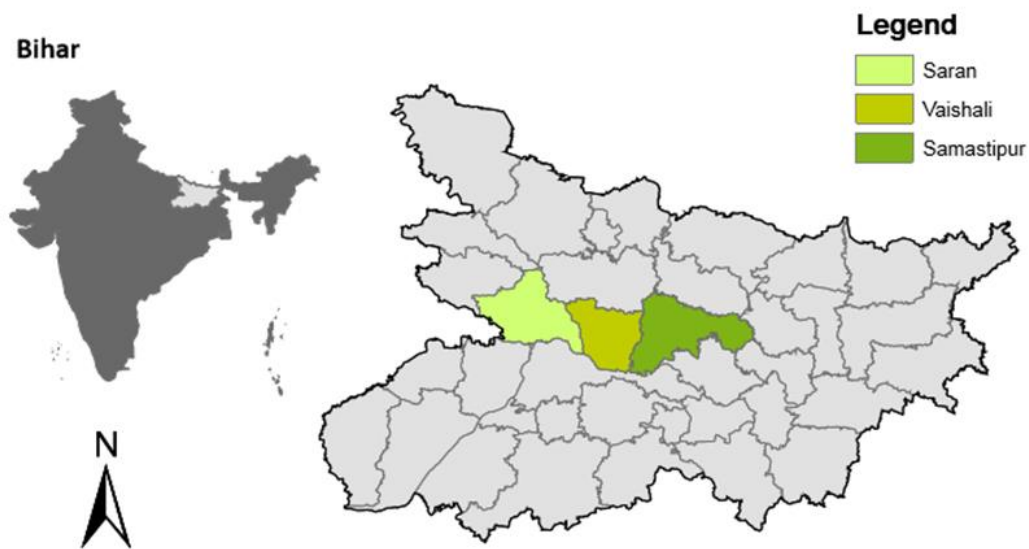
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181 **3. Context of the study**

182

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

187 **Figure 2.** Location of the study areas in Bihar, India.



188

189

190 Nevertheless, Bihar has always faced significant obstacles to economic growth and development (Jha
191 and Gundimeda 2019). According to Rasul and Sharma (2014), the state's poor economic
192 performance over the years is due to high population numbers with poor skills, its weak agrarian
193 structure, poor physical and economic infrastructures, issues of governance and institutional factors,
194 an unequal distribution of resources and scarce foreign direct investments. Bihar's poverty ratio
195 stands at 33.7% (Government of Bihar 2015) while the Human Development Index (HDI) is equal to
196 0.367 (Jha and Gundimeda 2019). According to the 2011 population census, Bihar is the third-most
197 populous state in India, with almost 8.6% of the country's total population (Chandra et al. 2018) of
198 which nine out of every ten people being rural residents (Jha and Gundimeda 2019). The literacy rate
199 is equal to 61.8% which is below the national rate of 74%. As previously stated, the economy of Bihar
200 is largely dependent on agriculture. Indeed, agriculture contributes to one-fifth (21.3%) of Bihar's
201 GDP and is the prime source of livelihood for about 90% of the population (Government of Bihar
202 2014). Several crops in different soil categories available in different agro-climatic zones are

203 cultivated. For instance, Bihar is the sixth largest fruit producer in India (Kumar 2018), while rice,
204 wheat, and maize are the major cereal crops. Rice is the main monsoon crop and is cultivated in all
205 districts of Bihar. Wheat was increasingly planted by Bihari farmers after the Green Revolution and
206 is currently the major crop of the winter season. Maize is also cultivated, with an average annual
207 production level of approximately 1.5 million tons and a steady positive trend in production. Pulses
208 such as mung bean, peas, and lentils are mostly grown in the southern parts of Bihar (Tesfaye et al.
209 2017; Government of Bihar 2014). However, 82% of landowners have less than one hectare of land
210 (Kumar 2018) and the economic condition of farming communities is still miserable (Ahmad et al.
211 2017). Furthermore, average productivity for most of the crops, except maize and pulses, is well
212 below the national average while population pressure is rising day by day (ibid.).

213 As for the exposure to the whims of an unpredictable climate, Bihar is definitely a disaster-prone
214 state, especially concerning floods and droughts (Majumder and Kumar 2019). The high vulnerability
215 of the state is due to the fact that Bihar forms a saucer-shaped valley located between the wet eastern
216 coastal regions and the moderately dry continental region of the western plain (Jha and Gundimeda
217 2019). This means that regional variations in precipitation distribution and precipitation variability
218 are much higher. Generally, the eastern and northern areas receive 2000 mm rainfall, whereas the
219 western and south-western parts receive less than 1000 mm rainfall (Aryal et al. 2018). Consequently,
220 southern Bihar is highly drought-prone, whereas northern Bihar is a highly flood-prone area
221 (Government of Bihar 2012).

222 Recent studies project a general increase in monsoon rainfall and increases in both minimum and
223 maximum temperatures across Bihar (Tesfaye et al. 2017; Kumar et al. 2006; Lal et al. 2001). The
224 magnitudes of rainfall and temperature changes will vary depending on the site, indicating that the
225 effect of climate change on crops will also vary by location (Tesfaye et al. 2017). This will be a major
226 risk for crop production across Bihar. Particularly, changes in rainfall could mostly affect autumn
227 crops while the increase in temperature, particularly minimum temperatures, could be a major threat
228 for winter and spring-sown crops. Furthermore, an increase in rainfall amount and intensity would
229 increase the chance of flash floods, flood conditions and lesser groundwater recharge, that in turn
230 would also lead to an increase in atmospheric humidity, and in the duration of the wet season (Mall
231 et al. 2006). Combined with higher temperatures, these conditions could favour the spread of fungal
232 diseases, or the incidence of insect pests and vectors (Sharma et al. 2007). This is clearly detrimental
233 to agricultural activities and food security, since small holdings of land are often not enough to keep
234 households out of poverty even in optimal farming conditions (Chand et al. 2011).

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

239

240 **4. Empirical Analysis**

241 *4.1. Sample and Data Collection*

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

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

266 The household questionnaire was translated into local language (Hindi) for better understanding of
267 enumerators and farmers. The data collection team consisted of three enumerators who attended a
268 four-day training and field-testing series. One enumerator was designated team leader and was
269 responsible for cross-checking all household data at the end of each day. The enumerators used
270 electronic tablets to record the data using the Open Data Kit (ODK) platform. All data was uploaded
271 to a server at the end of each day after being checked by the team leader. The household questionnaire
272 used was adapted from the Rural Household Multi Indicator Survey (RHoMIS) (Hammond et al.

273 2017) following enumerators' feedback during the training. RHoMIS is a household survey tool
 274 designed to rapidly record a series of standardized indicators across the spectrum of agricultural
 275 production and market integration, nutrition, food security, poverty and greenhouse gas emissions.
 276 The questionnaire also collected standard socioeconomic information about household demographics,
 277 education, landholdings, sources of income, migration, and the gender-disaggregated allocation of
 278 decision-making power.

279 **Table 1.** Sample Composition

District	Village	Participants	Non-participants	Total Sample
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
Sub-total		39	111	150
Samastipur	Dhobgama	0	20	20
	Harpur	32	16	48
	Madapur	14	5	19
	Mahamada	36	12	48
	Narayanpur	0	17	17
Sub-total		82	70	152
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
Sub-total		179	119	298
Total		300	300	600

280

281 4.2. Definition of the SRL concepts

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

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

- 290 i. *Human capital*: age and level of education of the household head, as well as the household size,
291 are selected for human capital-related variables. Age of the household head can be considered as
292 a proxy for farming experience (Patnaik et al. 2019; Deressa et al. 2009). Previous literature has
293 identified both positive and negative relationships between the number of years of experience
294 and the adoption of adaptive strategies (Maddison 2007; Shiferaw and Holden 1998). This study
295 hypothesizes that age of the household head positively influences the use of various adaptation
296 options. Highly experienced farmers are likely to have more information and knowledge about
297 various management practices, and how to adjust them based on changes in environmental
298 conditions and household needs. Similarly, a higher level of education facilitates access to
299 information about agro-climatic aspects, so farmers with higher levels of education should adapt
300 faster to climatic stressors (Below et al. 2012; Maddison 2007). Finally, the impact of household
301 size on the adoption of adaptation measures can be seen from two perspectives. First, a large
302 family size is usually associated with a higher labour force, which would allow a household to
303 perform various agricultural activities. Second, large households may be forced to divert part of
304 the workforce to non-agricultural activities in order to increase household income and alleviate
305 the consumption pressure imposed by a large family (Deressa et al. 2009). Consequently, a
306 positive relation is expected between the household size and the adoption of adaptation measures.
- 307 ii. *Social capital*: the level of trust and cooperation within the community is considered an indicator
308 of social capital (Krishna 2004). High levels of trust and cooperation within the community are
309 assumed to enable the adoption of adaptive strategies since social networks act as conduits for
310 information and encourage people to engage in mutually beneficial efforts (Goodwin 2003).
311 Female-headed households may have a lower ability to cope with climatic stressors since
312 traditional social barriers may limit their access to information and other resources, in which case
313 a negative relation is expected (Hassan and Nhemachena 2008; Tenge et al. 2004). Particularly
314 in Bihar, women belonging to certain castes are forced to stay out of the labour market and remain
315 confined to domestic duties (Government of Bihar 2020). Lastly, household participation in the
316 S4N program was included as a variable to account for this source of social interaction. This is
317 because the participation in program initiatives plays two distinct roles in the uptake of adaptive
318 strategies. First, trainings were meant to raise farmers' awareness about sustainable production
319 techniques and to build farmers' capacity for informed decision-making, all through hands-on
320 experimentation and frequent interaction for knowledge and experience sharing. Second, the
321 participatory approaches adopted by the program encourage the connection between and within

322 communities and farmers, expanding the social capital of the rural households and enabling them
 323 to have access to alternative livelihood opportunities. Here it is expected that households who
 324 have participated in the development program are more likely to adapt to climate change.

325 iii. *Natural capital*: farm size easily represents the endowment of natural capital (Deressa et al.
 326 2009). Since farm size is associated with greater wealth, it is expected that larger-scale farmers
 327 are likelier to undertake adaptive strategies than small-scale farmers would be (Aryal et al. 2014).

328 iv. *Physical capital*: the household appliance index has been calculated as the physical capital-
 329 related variable¹. A home with a stove, refrigerator, television or motor vehicle denotes a certain
 330 level of well-being, which is a determinant of the likelihood that a household will adapt
 331 (Kuntashula et al. 2015). Moreover, a variable measuring whether a household has land
 332 ownership rights was measured, since it may influence investment decisions and households’
 333 resilience (Mutabazi et al. 2015). When farmers feel secure about land ownership, it is likelier
 334 they will investment in adaptation options. Indeed, ownership of land act as a positive incentive
 335 in facilitating farmers to make investments in their farms.

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

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

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

Livelihood Assets	Expected influence	References
<i>Human Capital</i>		
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
<i>Social Capital</i>		
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
<i>Natural Capital</i>		

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.

Farm size	+	Aryal et al. 2014
<i>Physical Capital</i>		
Land ownership right (1 yes/0 no)	+	Mutabazi et al. 2015
Appliance Index	+	Gotor et al. 2018b
<i>Financial Capital</i>		
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

344

345 *4.3. Definition of the Livelihood strategies*

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

349 The first step in REBAS development is the selection of a set of variables related to the possible
 350 adaptive strategies (intensification, diversification, alteration and migration) that may contribute to
 351 the household's resilience. To compensate for a potential fall in yields, smallholders may choose a
 352 strategy of agricultural 'intensification' through the employment of yield-enhancing agricultural
 353 inputs (Speranza 2013; Paavola 2008). Consequently, in order to capture the presence of the
 354 intensification strategy, the number of different inputs (viz. fertilizer, manure, compost, pesticides
 355 and irrigation facilities) used for carrying out agricultural activities was counted². Therefore, the
 356 variable considered to capture the implementation of an intensification strategy will range from 0 to
 357 5. The diversification strategy included information on crop diversification (through the Simpson's
 358 Diversity Index) (Gotor et al. 2018b; Douxchamps et al. 2016; McCord et al. 2015), the use of
 359 intercropping with legumes by means of a dummy variable (Workayehu 2014; Rusinamhodzi et al.
 360 2012), the presence of other forms of on-farm diversification (coexistence of livestock and/or
 361 agroforestry) (De Giusti et al. 2019; Wilkins 2007), as well as off-farm diversification (i.e. the amount
 362 of off-farm income sources). Concerning the alteration strategy, the use of early-maturing, drought-
 363 resistant or flood-resistant varieties and the early harvest of crops have been used (Moniruzzaman
 364 2015; Cho et al. 2014; Kurukulasuriya and Mendelsohn 2008). That is, four different dummy
 365 variables related to the alteration strategy were considered. Finally, in the case of migration, the
 366 indicator used is a dummy variable that assumes a value of 1 if the household has access to remittances
 367 from migrated household members, 0 otherwise (Marchiori et al. 2013; Paavola 2008).

² The selection of variables mostly followed literature based on African context, since the lack of specific studies in India. This could affect the interpretation of the absolute value of the score.

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

$$C_{jk} = \sum_l a_k^l (X_j^l) \quad (1)$$

$$REBAS_j = \sum_k v_k (C_{jk}) \quad (2)$$

372 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
 373 variable and X_j^l are j -th household's values for l -th construct indicator. Moreover, $REBAS_j$ is the
 374 composite score of resilience-building livelihood strategies of j -th household and v_k is the variance
 375 accounted by the k -th principal component.

376 Finally, to obtain a standardized value, the REBAS was transformed into values ranging from 0 to
 377 100 as follows in Eq. 3:

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

378 $j = 1, 2, 3, \dots, N$

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

382 4.4. Definition of the livelihood outcomes

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

393 To determine the relation between the livelihood strategies (proxied by the REBAS index) and the
 394 livelihood outcomes, the Household Food Insecurity Access Scale (HFIAS³) was employed in this
 395 analysis (Coates et al. 2007). The HFIAS is a set of nine questions that covers a recall period of 30
 396 days⁴ and captures households' behavioural and psychological manifestations of insecure food
 397 access. Each of the nine questions is scored 0-3, with 3 indicating the highest frequency of occurrence.
 398 At the end, the scores for all questions are added together. The total HFIAS can range from 0 to 27
 399 allowing the household to be pinpointed on a spectrum that indicates a higher degree of food
 400 insecurity with a higher score.

401 4.5. *Econometric Model*

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

408 From an empirical point of view, a Tobit model with endogenous regressors (Eq. 4 – 5) was
 409 implemented to address censored data and endogeneity⁵. More specifically, the two-step procedure
 410 suggested by Newey (1987) has been followed for the parameters' estimation. In the specific case
 411 analysed, the identification of the causal effect of REBAS on the HFIAS (as hypothesised in the SRL
 412 framework) may suffer from some endogeneity bias, as the food security (HFIAS) may directly or
 413 indirectly influence the household adoption of livelihood strategies (REBAS) as well.

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

$$REBAS_j = z_{1j}\pi_1 + z_{2j}\pi_2 + u_j \quad (5)$$

414 Wherein, for each j -th households, $REBAS_j$ is the endogenous variable; z_{1j} is a $1 \times k_1$ vector of
 415 exogenous variables, with δ the relative parameter $1 \times k_1$ vector; z_{2j} is a $1 \times k_2$ vector of additional

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 hours. 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.

416 instruments. By assumption $(u_i, \varepsilon_i) \sim N(0)$. β is the parameter measuring the effect of REBAS on
417 HFIAS, and π_1 and π_2 are matrices of reduced-form parameters.

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

425 **5. Results and Discussion**

426 *5.1. SRL construct*

427 As previously illustrated, the initial part of the study identifies and quantifies the different concepts
428 embodied by the SRL framework, namely livelihood assets, livelihood strategies and livelihood
429 outcomes. The descriptive statistics of the variables employed in the analysis are presented in Table
430 3. Among the livelihood assets, the table shows that the average age of the household heads of the
431 sample is around 47 years with only 24% of them as female. The average household size in the
432 surveyed area is 7.57 people, with a minimum of 2 members and a maximum of 20 members. One-
433 tenth of respondents have a household size of 2–4 members, which is considered as a small family –
434 typically the husband, wife and two children. A large proportion of the households (62%) are medium
435 sized in terms of number of members, while only 10% of the households in the sample are extended
436 households with more than 12 members. Regarding the farms, 96% of the households claim to own
437 the land they cultivate. The average size of a farm is 1.50 acres, which is in line with the state average.
438 Land holdings in Bihar consist predominately of marginal (0–2.5 acres) and small (2.5–5 acres) farm
439 holdings with a high degree of fragmentation (Government of Bihar 2015). Almost 60% of the sample
440 finds it difficult to repay debts, while just a small percentage of people sampled have access to formal
441 or informal sources of credit (5% and 3% respectively). Credit is an important input to accelerate
442 agricultural production and productivity. Indeed, the demand for financial resources for cropping,
443 inputs and other machinery have been increasing in Bihar. However, the State does not have an
444 adequate financial structure capable of meeting this demand (Government of Bihar 2020).

445 Focusing on the livelihood strategies, the variable related to the intensification strategy presents a
446 mean value of 4.83, indicating that farmers employ almost all the agricultural inputs considered (viz.
447 fertilizer, manure, compost, pesticides and irrigation facilities). Due to the small size of people's
448 landholdings, and the general lack of off-farm opportunities in rural areas, smallholders are largely
449 forced to follow intensification strategies to generate enough income (Chand et al. 2011). Conversely,
450 the Simpson's Diversity Index is equal to 0.21. This is evidence that a strategy based on the
451 diversification of cultivated crops is not widespread among the rural households considered in the
452 analysis. Indeed, all the sampled households tend to focus their agricultural production on rice and
453 wheat. These results are in line with the state trend of rice and wheat together representing over 70%
454 of the total gross cropped area of Bihar (Government of Bihar 2020). Others crops cultivated by the
455 households in the sample are potatoes (83.50%), maize (56.50%), mustard (41.83%), pulses (13.83%)
456 and chili (8.50%). Moreover, the dummy variables associated with the alteration strategy present a
457 mean value above 0.70, except for the adoption of flood-resistant varieties that has a mean value of

458 0.50. Lastly, one-fifth (22%) of the sample received remittances from migrant household members.
 459 The combination of natural, economic, and social factors in Bihar push household members to
 460 migrate (Jha et al. 2018). At the same time, remittances help in the overall improvement of well-being
 461 for migrant households in Bihar. Tumbe (2011) found that the dependence on domestic remittances
 462 is much higher in Bihar than the average for India.

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

468 **Table 3:** Description of the Sustainable Rural Livelihood constructs and descriptive statistics of the
 469 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	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	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

470

471

472

473 5.2. *Identification of the livelihood strategies*

474 Once the empirical construct of the SRL framework was established, the next step concerned the
475 calculation of the resilience-building adaptive strategies (REBAS) index, reflecting the portfolio of
476 adaptive strategies adopted by the farm households and their correlations. The computation of such
477 an index is based on an objective weighting scheme derived from the PCA of the dataset⁶. Table 4
478 illustrates that the first component of the PCA is based on all the alteration practices, i.e. the adoption
479 of drought- and flood-resistant varieties, early-maturing varieties and the adjustment of harvesting
480 dates according to weather conditions. Migration (receiving remittances) and a subset of
481 diversification strategies (namely carrying out off-farm activities) have highest loadings in the second
482 component. Two different practices of an on-farm diversification strategy (the integration of livestock
483 and/or agroforestry and intercropping with legumes) have maximum loading in the third component.
484 The last component shows a high correlation between the identified intensification measure (viz.
485 amount of inputs used in the agriculture activity) and a subset of diversification strategies (namely
486 crop diversification).

487 These results illustrate the internal correlations among the different classes of adaptive strategies
488 identified in the study (intensification, diversification, alteration and migration). The diversification
489 strategies observed within the sample population are comprised of on-farm diversification and
490 intercropping with legumes. Intercropping with legumes is an appealing option to address climate
491 risk for farm households, because it can reduce the risk of crop failure and improve productivity
492 (Workayehu 2014; Rusinamhodzi et al. 2012). On-farm diversification activities include the
493 integration of crops and agroforestry and/or livestock. Tree-based systems are able to maintain
494 production during wetter and drier periods and to mitigate climate change through enhanced carbon
495 sequestration (Verchot et al. 2007). Raising livestock in mixed crop-livestock systems is a common
496 practice in India, as a substantial share of animals' energy requirements comes from crop by-products
497 and residues (Birthal et al. 2014). Furthermore, local integration of cropping with livestock systems
498 would allow greater flexibility of the whole system to cope with potential socio-economic and climate
499 change induced threats and improve the quality of grasslands through periodic renovations (Lemaire
500 et al. 2014; Di Falco et al. 2011; Wilkins 2007; Russelle et al. 2007). Households tend to combine
501 different diversification strategies within a portfolio as a sort of “insurance” against unpredictable,
502 future stressors. The fact that on-farm diversification and intercropping with legumes present a high
503 positive correlation indicates that Indian farmers tend to adopt a portfolio of strategies that reduce 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.

504 risk of crop failure while providing an alternative source of income if the crop failure actually occurs.
505 This is in line with the study by Beillouin et al. (2019) which shows that a combination of different
506 diversification strategies can generate better results than the adoption of a single strategy. The second
507 and fourth components of the PCA instead highlight that some strategies are considered by Indian
508 farmers as alternative strategies. Not surprisingly, diversification beyond on-farm activities and
509 migration are negatively correlated, as is the intensification strategy and the strategy based on
510 interspecies diversification. Only the alteration strategy is adopted by rural households as a stand-
511 alone measure. The PCA does not reveal hidden correlations with other adaptive strategies.
512 Considering that Bihar is a state particularly sensitive to climatic whims, especially droughts and
513 floods, it is intuitive that farmers tend to introduce stress-resistant crop varieties that better suit the
514 local conditions they face and also adjust harvesting dates according to weather conditions.

515 **Table 4:** PCA components used for resilience-building adaptive strategies (REBAS) index
516 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

517

518 5.3. SRL relationships

519 The final part of the study analyses the relationships between livelihood resources, livelihood
520 strategies and livelihood outcomes as indicated by the SRL framework. To assess this objective, a
521 Tobit model with endogenous variables was implemented. Results of this part of the study can be
522 found in Table 5⁷. The results of the first stage of the model bring out a number of insights about the

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

523 linkages between the livelihood assets and the identified strategies. Social capital-related variables
524 have a significant positive effect on the resilience-building measure. This is in accordance with
525 previous studies (Mutabazi et al. 2015; Isham 2002). High levels of trust and cooperation within the
526 community have been shown to reduce social barriers that may hamper the employment of adaptation
527 strategies (Groenewald and Bulte 2013). Interestingly, the model shows that female-headed
528 households are more likely to take up climate change adaptation methods. This could be related to
529 the fact that women are deeply engaged in agricultural work and therefore have greater experience
530 and access to information about management and farming practices (Nhemachena and Hassan 2007).
531 This result is interesting since in Bihar women tend to be excluded from all forms of economic
532 activity, including those within their own farms, due to socio-cultural restrictions (Government of
533 Bihar 2020). However, in the rare cases women are indeed the head of the household, they seem to
534 be conducting the role effectively, especially regarding the management of their farms. Likewise,
535 participation in the S4N program is associated with a higher level of adaptation. From this it is
536 possible to assert that the program was able to provide the information and tools needed to stimulate
537 the implementation of appropriate strategies to adapt to climate stressors.

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

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

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

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

581

582 **Table 5:** Results of the Tobit regression with endogenous variables

Variables	Regression results		
	Coef.	SE	z
<i>REBAS Index</i>			
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 ***
<i>HFIAS</i>			
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

583 $n = 600$; Level of significance: * 10 %; ** 5 %; *** 1 %;584 R^2 (REBAS eq.) = 38.32; Wald χ^2 (HFIAS eq.) = 57.41 (p -value <0.001); Wald test of
585 Exogeneity $\chi^2 = 7.69$ (p -value = 0.006); Sargan test of overidentifying restriction $\chi^2 = 1.45$ (p -
586 value = 0.228).

587

588 6. Conclusion

589

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

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

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

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

620 specific livelihood strategies, while in other cases (3) some livelihood assets could be directly linked
621 to livelihood outcomes.

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

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

651 Further research could improve the methodological approach of the current analysis by including
652 more predictors of adaptation, such as variables that describe farmers' perceptions and attitudes

653 toward climatic risks, or by extending the range of livelihood outcomes that could be pursued by the
654 households, such as yield stability or the sustainable use of natural resources.

655

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665

666 **Compliance with ethical standards**

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668

669 **References**

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