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Research article

Rural households' livelihood adaptation strategies in the face of changing climate: A case study from Pakistan

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ABSTRACT

Rural and agricultural communities' adaptation to climate change has gained significant attention owing to many countries' vulnerability to climate change risks. A similar trend has been witnessed in South Asia, a highly climate-vulnerable region, where research has grown dramatically considering the agriculture sector's vulnerability to climate-induced disasters. However, little attention has been paid to the adaptation of the livelihoods of rural households. This research, therefore, takes the case of Pakistan to explore livelihood adaptation strategies of rural households to climate change and investigate the factors that expedite or halt the adoption of livelihood diversification strategies. A multistage sampling design is used in this research, where 480 rural households from the Punjab province of Pakistan were selected and interviewed using stratified and random sampling approaches. A multivariate probit (MVP) regression model is employed to analyze the factors affecting households' adoption of livelihood adaptation strategies. The results show that besides adaptation of agronomic operations (agricultural adaptation strategies), rural households in the study area employed a wide range of strategies to adapt their livelihoods to climate change. These strategies include poultry and livestock farming, value addition of farm produce, trading of animals and farm commodities, small businesses (shops, etc.), daily wage labor, horticultural crop farming, and non-farming jobs. The estimates of the MVP model revealed that respondents' education, household size, income, access to a credit facility, access to farm advisory services, and access to climate forecasts have significantly influenced the choice of livelihood adaptation strategies. Based on these findings, this research recommends that the authorities should make efforts to improve farmers' understanding of the adaptation of climate change risks and educate them to adopt multiple livelihood options to improve the resilience of their livelihoods to climate-induced risks. This research has important policy implications for other countries with similar socio-economic features.

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1. Introduction

Climate change and its induced disasters have become more frequent and severe during the past few decades, having severe ramifications for many sectors of countries around the world [1,2]. The changes, such as temperature fluctuations, rainfall variability, and shifts in the arrival of seasons, have triggered various risks, especially in sectors such as agriculture [3,4]. Agriculture is more susceptible to climate change risks because of its direct dependence on environmental variables, temperature, and precipitation. Therefore, given such changes, crop production in various regions around the world is faced with yield declines and crop failures [5,6]. South Asia is reported among the world's most climate-vulnerable regions owing to the nations' higher dependence on agriculture and associated sectors [7,8]. This implies that climate change-induced hazards have posed huge risks to the livelihood of rural people in the region, threatening their subsistence and food security.

Like other nations in the region, Pakistan is faced with the growing challenge of extreme weather events, mainly associated with rising temperatures [9]. Since 1960, the country has become warmer by nearly half a degree Celsius [10]. This rise in temperature has triggered various crop hazards, such as extreme floods, droughts, and changing rainfall patterns [11,12]. Floods, for instance, have become a regular event, repeating every couple of years. The recent unprecedented floods of 2022, which surpassed the previous historic floods of 2010 in terms of economic loss of US$10, have wreaked havoc in the country [13,14]. The 2022 floods displaced 33 million people across the country, causing the tragic loss of precious human lives, livestock, and crops, causing estimated damage of over US$15 [13]. Similarly, extreme drought in the late 1990s and early 2000s is another example of climate change-associated crop hazards [15]. These disasters are extremely alarming for a country like Pakistan, which mainly depends on agriculture for major economic activity. Agriculture generates over 22% of the country's gross domestic product (GDP) and employs 38% of its labor force [16]. In a country of 208 million, where the majority lives in rural areas (60%), these statistics imply that the livelihoods of the rural population could be extremely vulnerable to climate-induced disaster risks [17]. In this scenario, rural households can adapt their livelihood to disaster risks by opting for alternative income options.

Livelihood adaptation refers to the process or adjustment by which households lessen the adverse impacts of climate change risk on their livelihood and well-being and also take the opportunity to profit from the change [18]. Studies show that adaptation is a useful strategy to mitigate the adverse impacts of climatic disasters on rural livelihoods [19–22]. Livelihood adaptation could be either on-farm or off-farm adaptation. In on-farm adaptation, rural households (mainly farmers) make adjustments to the cropping operations in line with climate changes in the form of shuffling crop cultivation dates, input application, and soil and water management methods [23,24]. Off-farm adaptation, however, defines a broader set of activities that expand to various non-farm occupations. It can be in the form of modification in the current livelihoods or a complete shift in the source of earning. Increased dependence on farm-related ventures such as poultry or livestock farming, shift to horticultural crops, off-farm jobs, migration to urban areas, and changes in diet consumption are the key off-farm livelihood adaptation strategies reported in the literature [18,25].

During the past two decades, research on climate change adaptation has grown significantly owing to its adverse impacts on the agricultural sector. A wide range of studies explored various dimensions of agricultural climate change by investigating adaptation in crop farming, drivers of adaptation, and associated constraints. For instance, Khan et al. [12] explored adaptation strategies in rice farming and explained that farmers' age education and availability of irrigation water positively influence farmers' adaptation to climate change. Sargani et al. [26], in their study in Sindh Province, reported that human and financial assets have substantial effects on smallholders' adaptation strategies. Usman et al. [27] found that farmers' adaptation strategies, such as management of crop variety, soil and irrigation water, diversification of agriculture production systems, and management of fertilizer and farm operations time, are shaped by various factors, including education, household size, off-farm income, remittances, credit access, and access to information about climatic and natural hazards. Shah et al. [28] measured the vulnerability and adaptation of farmers in the KP province of Pakistan. They suggested that farmers' vulnerability to climate change can be modulated by improving their adaptation to crop farming. In Ethiopia, Sertse et al. [4] state that farmers adopt a wide range of strategies, including new seed varieties, agroforestry approaches, and water conservation measures, to cope with adverse climate effects. Some studies have also evaluated the efficacy of agricultural adaptation on farm income, food security, and rural poverty. Khan et al. [29] evaluated the impact of adaptation strategies on rice yield and concluded that adaptation positively affects rice yield and farm income and reduces rural poverty.

Despite the growing literature on these on-farm adaptation measures, the existing research has not focused much on off-farm adaptation strategies or livelihood adaptation. Especially in Pakistan, where no existing research (besides Shah et al.'s [28] study in KP province in Pakistan) explores the rural household's livelihood adaptation to climate change, especially in Punjab province, which is the major agricultural region most vulnerable to climate change. Further, recent studies in other provinces did not analyze livelihood adaptation strategies and their drivers [30,31]. Therefore, to fulfill this research gap, this research intends to explore the livelihood adaptation of rural households in Punjab province. The research has three research objectives: 1) to explore the climate-induced disaster risks reported by the rural households in the study area, 2) to find out the livelihood adaptation strategies of rural households, and 2) to analyze the factors shaping rural households' choices of various livelihood strategies.

The remainder of the paper is as follows. Section two describes the theoretical model and conceptual framework of the study. Section three explains the methods, description of research sites, and empirical model for data analysis. Section four outlines key findings and presents the discussion; section five concludes the research findings and highlights key recommendations.

2. Adaptation to climate change in agriculture: a review of relevant theories

Literature shows various behavioral theories and models that are used in similar studies and have evolved over the years. These theories conceptualize individualistic intentions of the adoption of technologies or practices in the context of agriculture. The most common ones include the Theory of Planned Behavior (TPB) [32], which has evolved from the Theory of Reasoned Action (TRA) [33], the Values Beliefs Norms Theory (VBN) [34], the Protection Motivation Theory (PMT) [35,36], and the Model of Private Proactive Adaptation to Climate Change (MPPACC) [37], which draws on the PMT.

TRA and its later version, the TPB, follow the proximal causes of an individual's behavior and emphasize intra- and interpersonal factors such as attitude toward the behavior and subjective norm [32,38]. In contrast with TRA, TPB considers perceived behavioral control as an additional attribute that deals with an individual's perception of personal control of certain behaviors. TRA and TPB are particularly pertinent in explaining how these associated factors influence individuals' intentions about certain beliefs or behaviors. Nonetheless, they only provide little or no details about intrapersonal attributes such as people's experiences, emotions, or habits and, therefore, lack attributes related to socioecological context factors. Like TRA and TPB, VBN also has limitations in terms of providing insights on socio-economic and environmental context factors as it primarily considers the normative impact on behavioral intentions. According to VBN, environmental beliefs are shaped by an individual's personal values and norms, and these values are activated when an individual understands that his or her actions can negatively influence the outcomes important to him or her. Pro-environmental behavior is shaped by personal values, an individual's personal beliefs about the environment, associated causes and impacts, adaptive capacities, and moral norms [34]. Likewise, the PMT suggests that individuals' cognition of environmental hazards and their intentions to avert them change their behavior to protect themselves [39]. The PMT is mainly based on two processes, environmental hazards and coping appraisal, and does not consider social and environmental factors. These two processes (environmental hazards/climate risk and coping appraisal) were later integrated with socioeconomic and environmental context factors by Grothmann and Patt [37], who named the Model of Private Proactive Adaptation to Climate Change or MPPACC.

2.1. Theoretical model and conceptual framework

This study chose the theoretical Model of Private Proactive Adaptation to Climate Change (MPPACC) as a heuristic for this empirical research [37]. The MPPACC adequately fits in the current study context and helps in understanding rural households' climate risk and adaptation appraisal and their relationship with household-level adaptation decisions by taking into account pivotal socio-cognitive context attributes. By adapting MPPACC in the current study context, we assume that a rural household (head) assesses risk in the first step before considering diversifying (or changing) the livelihood source, called climate risk perception or climate risk appraisal). Afterward, the rural household assesses its subjective capability to deal with the posed risk as a second step, referred to as adaptation intention or adaptation appraisal in MPPACC. Both these stages are marked as critical in determining the actual adaptation of rural households' livelihoods, which eventually shape their vulnerability or resilience to climate change and associated disaster risks [40,41]. Climate risk and adaptation appraisal are influenced by various socio-economic attributes of rural households [4]. To choose the socio-economic and other context factors, we followed the approach used by Schmitzberger et al. [42] that includes farmers' socio-economic and farm-related drivers among key adaptation determinants. Besides, we considered external factors such as institution-led services such as credit and farm advisory. The MPPACC does not particularly describe the motivation of climate change

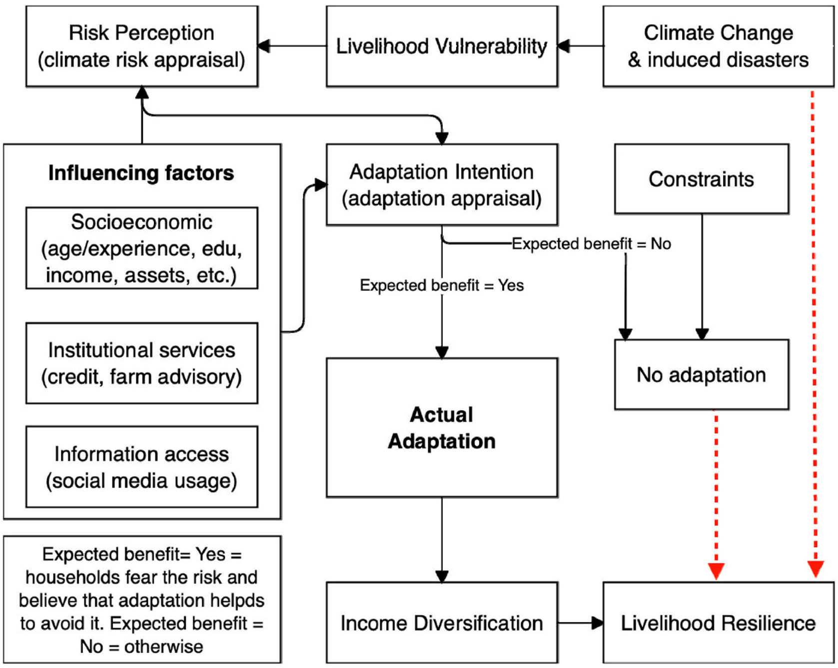

Fig. 1. Theoretical model of rural households' adaptation to climate change (guided by MPPACC [37]).

and adaptation appraisal; therefore, we first select livelihood vulnerability to climatic risks and disasters as the impetus of adaptation. Fig. 1 shows the conceptual framework where we have modified and adapted key components of the MPPACC according to our study. One of the limitations of the model is that it did not include households' access and exposure to contemporary information sources, such as social media, which is closely related to their adaptation decisions; thus, this study adds social media usage among the factors that shape rural livelihoods' vulnerability and adaptation.

This conceptual framework describes that given climate change and induced disasters, such as droughts, floods, and other biological hazards, rural households, which mainly rely on crop farming, face severe threats to their livelihoods. This implies that either they adapt to these risks and diversify their livelihoods by shifting their income source from farming to other associated businesses or face the risks in the form of reduced farm income, crop failures, etc. Higher exposure and susceptibility of crops to such production risks increase their livelihood vulnerability [41]. After this stage, given the extent of vulnerability of their livelihoods, households' climate risk appraisal or risk perception is determined. The households will evaluate the disaster risks posed to crops and thus intend to make changes in their livelihood sources, which defined adaptation intentions. At this stage, various internal and external factors, such as socio-economic and institution-provided services, influence their adaptive decisions. For instance, the household head with higher education, awareness of climate risks, and information about alternative earning options might successfully adapt to climate change, while constraints in the form of lack of finance, information, or positive attitudes might lead to no adaptation, keeping the livelihood vulnerable to climate change [25]. Similarly, households who take adequate measures to shift their source of livelihood and are able to diversify their income sources have more resilience to climate change and induced disaster risks.

3. Research site and methods

3.1. Research site

This research was conducted in the Punjab province of Pakistan, the country's most populous and major agricultural region [34]. Punjab constitutes over half of the national economy and is home to major cereal crops exported globally; it produces over 70% of the total cereal crops produced in the country [43]. The reason for choosing this region as the focus of this research is because of its agricultural significance and vulnerability to climate change. It is reported that this major agricultural region is extremely prone to various climatic and associated risks, which have posed serious threats to rural livelihoods [41,44]. In a province that has over half of the country's total population (110 million, 52% of the country's total population), where the majority reside in rural areas and are associated with farming and related businesses means that livelihoods these rural households are extremely vulnerable to climatic risks

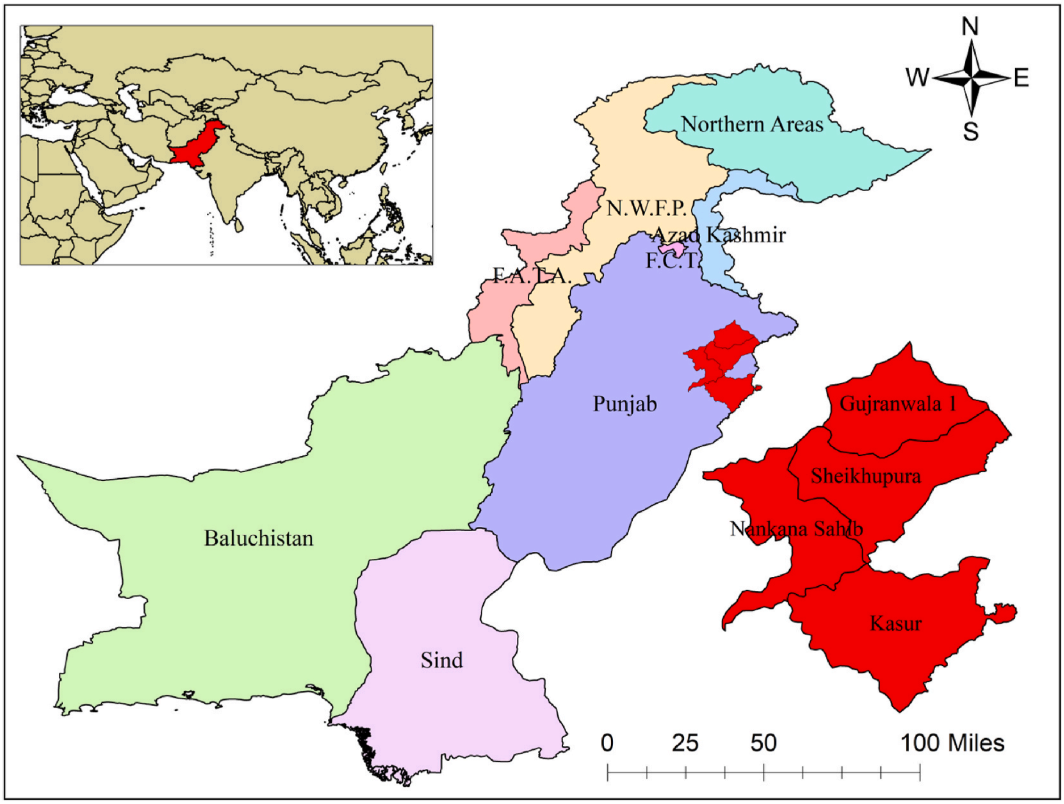

Fig. 2. Pakistan's location in Asia (left) and Pakistan's provinces and location of study districts in Punjab (middle).

[17]. For instance, studies report that in the Punjab province, climate change has adversely affected major crops [5,45]. Not only crops but also other associated ventures, such as livestock, also face serious risks associated with extreme temperatures, floods, droughts, and erratic rainfalls [13]. In particular, regions such as mixed cropping zones are extremely susceptible to these hazards as rural households mainly depend on crop farming to earn livelihoods. Since climatic and associated hazards have posed risks to these rural people's source of income, this research intends to find out how people in mixed cropping zone adapt their livelihood to climatic risks. Specifically, four districts were chosen from the mixed cropping zone.

3.2. Sampling and data collection

This research adopted a multistage sampling design to select the sample households from the selected research site. Punjab province was chosen in the first stage due to its agricultural significance and vulnerability to climate risk. In the second stage, the mixed cropping zone of Punjab was chosen for being the key region producing major crops. We selected four districts from the mixed cropping zone in stage three by using simple random sampling. These districts include Gujranwala, Sheikhupura, Nankana, and Kasur, which are shown in the following map (Fig. 2). In the fourth stage, we selected two subdistricts from each district. In stage five, two union councils or UCs were chosen randomly from each subdistrict, making a total of sixteen UCs. In the study area, there are two types of UCs: rural and urban UCs. Since this study mainly dealt with rural households, only rural UCs were taken into consideration. At step six, we chose two villages per UC, making a total of thirty-two villages. In the seventh and final stage, fifteen households were selected from each village using simple random sampling, which constituted a total sample of 480 rural households. Fig. 3 shows the sampling stages and subtotal at each stage; for detailed statistics, see Table A1. All data were collected in face-to-face interviews using a predesigned structured questionnaire.

The questionnaire's key components included information about respondents' socioeconomic attributes, their perception of the key climate and induced risks posed to their livelihoods, and their major livelihood adaptation strategies in response to climate risks. Before the actual survey, a pretest was carried out on thirty rural households outside the sample to ensure the validity and reliability of the questionnaire. We conducted a reliability test with an acceptable Cronbach alpha value of 0.784. The pretest helped us address some issues with the order of the questions, removal of some double-barreled questions, and accumulation of unnecessary information and has improved the clarity of the questionnaire. Two enumerators from a local university were hired and trained to assist with the field survey. The data collected was completed between June and August 2019.

3.3. Empirical models for data analysis

3.3.1. Determinants of livelihood choices: multivariate probit model (MVP)

During the survey, we found that households in the study area used multiple livelihood measures to cope with climate-induced disaster risks rather than relying on a single measure. This implies that their choice to adopt one strategy might depend on the choice to adopt another– allowing the possibility of correlation between dependent variables (livelihood strategies). This also infers that the error term of the regression model of one strategy may correlate with that of another because the decision to adopt a certain livelihood strategy is taken at the household level [46]. Therefore, the multivariate probit (MVP) model appeared to be a good fit as it addresses the issue of estimation bias and covers the possibility of correlation among dependent variables (livelihood strategies) and resulting correlation among error terms [46–48].

Assume an i-th rural household ($i = 1, \ldots, N$) making a choice on whether or not to adopt a certain livelihood strategy. Let U_k^* represent the advantages of adopting the kth practice and U_0 represent the advantages to the household for not adopting, where k depicts the decision to choose poultry farming, livestock rearing, trade of farm produce, a job in the nearby town, and small businesses as livelihood diversification options. The household prefers the k-th practice if $Y_{ik}^* = U_k^* - U_0 > 0$, with Y_{ik}^* showing the net benefit from the adoption of the k-th measure. Y_{ik}^* is unobservable because it is subjective. Alternatively, it can be represented as a latent variable function as follows:

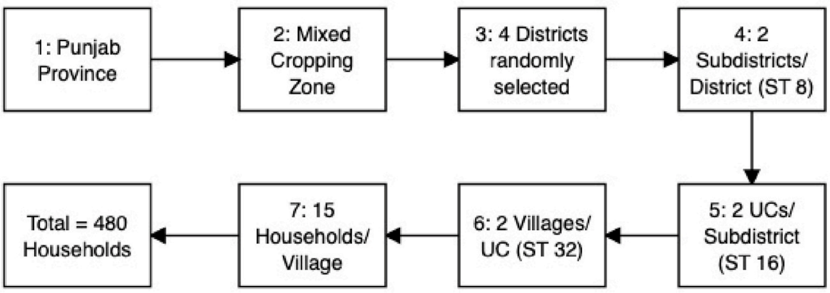

Fig. 3. Sampling stages (ST refers to subtotal).

$$Y_{ik}^{*} = X_{i}^{'}a_{k} + C_{i}B_{k} + SMU_{i}^{'}\gamma_{k} + \varepsilon_{ik}, Y_{ik}^{*} = \begin{cases} 1 & if Y_{ik}^{*} > 0 \\ 0 & otherwise \end{cases} \tag{1}$$

where Y_{ik}^{*} is a latent variable representing the probability of adopting livelihood adaptation measure k. Y_{ik}^{*} is observed by binary observed variable y_{ik}, with $y_{ik} = 1$ if livelihood adaptation measure k is adopted a by households and $y_{ik} = 0$ otherwise.

$X_{i}^{'}$ represents a vector of explanatory variables such as socio-economic attributes (e.g., age, education, and household size); C_i is a dummy variable capturing whether a household has accessed advisory through; $SMU_{i}^{'}$ is a vector of variables capturing the usage of social media by household heads. Table 1 provides details of names, definitions, and summary statistics of the explanatory variables. a_k, B_k and γ_k are parameters to be estimated; and ε_k is an error term. Equation (1) is estimated by the Geweke–Hajivassiliou–Keane (GHK) simulation method for maximum likelihood estimation, using the Stata commands "mvprobit" [49,50].

4. Results and discussion

4.1. Climatic and induced risks posed to rural livelihoods

This study first explored the risks rural households' livelihoods are exposed to and found that respondents mainly reported those risks and adverse impacts that are related to agriculture (Fig. 4), which is the primary occupation of most of the rural population in Pakistan. They reported an increase in farm input prices (99%) due to supply chain disruption because of climate-induced disasters such as floods, followed by an increased incidence of diseases and insect attacks (97%), a shift in rainfall patterns (90%), and depletion of water resources (90%). A significant majority also reported a decline in overall precipitation, a rise in temperature throughout the year, and a rising frequency of droughts.

These results show that rural households are extremely concerned about the risks posed to their farming. Farm input is a key determinant of farmers' income and crop returns; therefore, a rise in fertilizer and pesticide prices poses a huge challenge to farmers' crop returns. Diseases and crop attacks are other challenges reported by many other studies in Pakistan [51–53]. A rise in the frequency of crop insect attacks and disease outbreaks, reportedly associated with climate variation in the country, also poses huge threats to rural populations' livelihoods. The actual climate trends in the study area also support the reported decline in precipitation and rise in temperature. For instance, Khattak et al. [54] found a decline in average precipitation and a rise in temperature in the study area.

Regarding frequent droughts reported by the ranchers, a study supports the perception of rural households that Punjab has seen frequent dry spells in the past two to three decades [15]. Variations in temperature and precipitation have resulted in a shift in cropping colanders, which hampers the agricultural operations, supply chain, and, eventually, crop yield to a larger extent. Rural households reported that they are unable to keep up with the shifting cropping seasons. For instance, a study [55] on farmers' climate adaptation strategies in Pakistan reported that the winter cropping season has shrunken, posing risks to the cultivation of many crops. This implies that climatic and induced risks adversely impact Pakistan's rural livelihoods. These findings show that because the majority of rural households depend on agriculture and related occupations, most of the reported risks are crop hazards.

In addition to agriculture-related risks, respondents also reported social risks, such as a rise in food insecurity and migration or displacement, among key implications of climate disasters. Recent studies report that a huge population is being impacted by disasters such as floods. For instance, the recent floods of 2022 have displaced over 33 million people, resulting in an economic loss of over US $15 billion [13].

4.2. Households' livelihood diversification in response to climatic risks

The results (Fig. 5) imply that rural households in the study area have adopted multiple strategies to diversify their livelihoods in

Table 1
Name, definitions, and summary statistics of the explanatory variables.

Variable Name	Variable type & description	Mean	Standard deviation
Age	Continuous (years)	47.246	11.903
Education	Continuous (years of schooling)	7.533	4.415
Household size	Continuous (household members)	6.580	1.591
Landholding	Continuous (number of Acres[a])	8.073	6.885
Land ownership	Dummy (1 = farmer is owner, 0 = No)	0.886	0.317
Irrigation pump	Dummy (1 = owner, 0 = No)	0.640	0.480
Household workforce	Continuous (number of active workers/household)	1.98	1.199
Household income	Continuous (monthly income, 000 PKR[b])	11.050	10.880
Farm advisory	Dummy (1 = advisory services access, 0 = No)	0.420	0.494
Credit service	Dummy (1 = household has access, 0 = No)	0.326	0.469
Climate information	Dummy (1 = information access, 0 = No)	0.613	0.487
Social media usage	Dummy (1 = usage, 0 = No)	0.346	0.476

[a] Land unit in Pakistan (1 ha = 2.47 acre).
[b] PKR = Pakistani rupees (1USD = 163 PKR on 30 June 2019), (source: field survey, 2019).

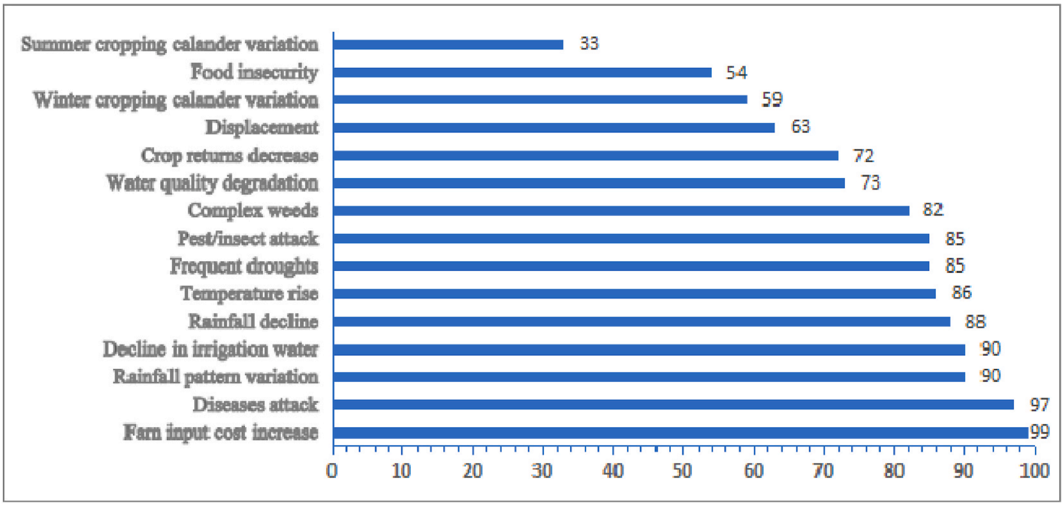

Fig. 4. Climatic and associated risks posed to rural livelihoods.

the face of climate-induced risks and disasters.

The majority of the respondents (26%) indicated poultry and livestock farming as an adaptation measure in response to climate-induced disasters. Farming of poultry birds such as chickens and ducks is a common practice in most rural households in Pakistan. Such medium- and small-scale interventions help rural people obtain essential food supplies and income by consuming and selling eggs and meat. Besides, they opt for animal husbandry in order to earn extra income by selling milk and calves from their herds. These strategies also serve as a safety net. For instance, if some medical emergency arrives or if the crop needs sudden treatment after heat shocks, households can sell a unit of their livestock herd and obtain quick cash to meet their immediate needs. Another study in Ghana [56] also reveals that rural households diversify livestock farming as a response to adverse impacts of climate risks on their crops. In contrast, a study in Peru [57] found a decline in livestock farming as an adaptation strategy to cope with declining profits due to climate impacts on crop farming.

Following these two most adopted livelihoods measures, 22% of households reported that they had started a non-farm job or started trade of agricultural commodities such as grains or farm inputs. Around 15% of the respondents stated that they had opened small businesses (such as general stores, shops, etc.) in order to earn livelihoods and feed their families. These estimates show an increasing trend of non-farming jobs due to climate risks-led declines in profits from crop farming. Such estimates are supported by the official agricultural statistics of the study area [58] that reveal a shrinkage of farmland under cultivation of major crops such as rice (a 10% decline in rice cultivation area during 2010–2020), which is seriously undermining the country's food security. In such a situation, when most tenant farmers who also need to pay the additional cost of land rent quit farming and opt for non-farm work and business by finding a job in a nearby town or starting a small store in the village. Our results are supported by another study [25] that revealed that

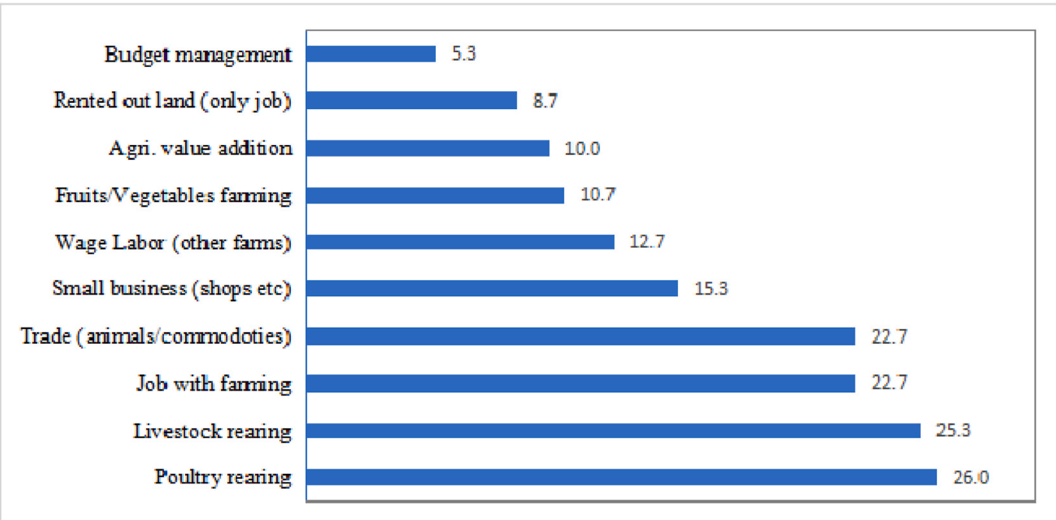

Fig. 5. Households' livelihood strategies in response to climatic risks.

most rural households are inclined towards non-farm adaptation strategies to adapt their livelihoods to the disastrous impacts of climate change. Similarly, some households tend to be involved in trade by buying, stocking, and then selling farm produce to urban markets, as they believe farming is not a viable option to rely solely on in order to feed their families.

Moreover, some households with no capital to start any off-farm business simply opt for work as farm laborers on others' farms in the village. Many landlords that have large farming activities tend to hire local people for their farm work on daily wages ranging from 500 to 800 Pakistani Rupees (US$2–3), which is a source of income for most of the lowest-income groups of the villages. Since the past few decades, there has been an upward trend in livelihood activities. Climate change is making it harder for tenant farmers to practice agriculture as farming calendars keep changing and crop returns are highly variable, making farming a risky venture for leased farmers. Therefore, they opt for other livelihood options that contain minimum risk and guaranteed income. Previous studies [51,59] show a significant relationship between farmers' risk preferences and their socio-economic levels; farmers who are earning less income are more likely to be risk averse as they do not have multiple livelihood options.

Several rural households also stated an inclination towards cultivating vegetables, stating that they are short-term, less labor-oriented, and have fewer risks of being impacted by crop failure compared with agronomic crops. It was found that households tend to grow vegetables because of more crop return and the fact that it also provides them an opportunity to meet the food demands of households. Most farmers reported cultivation of horticultural crops at a small scale mainly to use the vegetables at home or sell them in their close social circle. Our results contradict the case of China, where vegetable farmers tend to grow more agronomic crops to adapt to climate change [60]. This variability could be due to differences in climate conditions in both countries.

Furthermore, respondents also stated localized processing of food products at the domestic level to add value to their farm commodities. Specifically, they reported the production of butter and cooking oil from milk, jaggary from sugarcane, and the processing of rice to sell to other farmers and nearby towns to earn a decent profit that is not possible by selling the raw commodities. Farmers tend to do this because of the stagnant market rates of their farm produce relative to the rising input cost to produce them. Further, the rise in climate-induced disasters also makes it hard for them to practice conventional farming; thus, they find such ways to earn additional profit to cope with growing uncertainties in the local markets. A number of studies advocate agriculture value addition as an alternative strategy for rural development owing to its potential to increase farmers' income within the existing resources and improve their climate resilience [61,62]. Besides these strategies, a small number of households stated that they have rented out the land to other farmers in an attempt to quit farmers for other professions.

4.3. Factors shaping households' choices of various livelihood strategies

4.3.1. Descriptive statistics of explanatory variables

Summary statistics of the selected attributes (Table 1) report the household heads' average age to be 47 years with seven years of schooling and a household size of over six persons. This implies that the majority of respondents belong to middle and old-age groups, have less formal education, and have large families to support. Similarly, on average, they had eight acres of farming land, where the majority (88%) indicated themselves as farm owners rather than tenants, which means that the rest of the households might be farming on leased land or they may be doing non-farm businesses. In terms of farm-related possessions, over two-thirds reported ownership of an agriculture borewell (called tube well), which serves as the major source of crop irrigation owing to a meager supply of surface water (canal water) [59]. Furthermore, on average, a household had nearly two persons available to work as laborers to earn and contribute to the family income, which appeared to be eleven thousand Pakistani rupees (US$1 = PKR119). Regarding institution-led

Table 2
Determinants of livelihood diversification: Estimates of MVP model.

Explanatory variables	Poultry farming	Livestock rearing	Trade of farm produce	Job in nearby city/town	Small businesses
Age	0.011 (0.009)	0.015 (0.009)	−0.003 (0.010)	−0.004 (0.013)	0.006 (0.010)
Education	−0.062* (0.034)	−0.046 (0.036)	0.004 (0.037)	0.280*** (0.054)	−0.011 (0.039)
Household size	0.108 (0.068)	−0.029 (0.072)	−0.038 (0.076)	−0.297*** (0.096)	−0.197** (0.077)
Landholding	−0.032* (0.018)	−0.058** (0.025)	−0.048** (0.021)	−0.089*** (0.026)	0.012 (0.017)
Land ownership	−0.483* (0.279)	−0.596** (0.302)	−0.839*** (0.300)	5.887 (139.547)	−0.323 (0.308)
Irrigation pump	0.199 (0.214)	0.119 (0.229)	−0.271 (0.230)	0.727** (0.296)	0.313 (0.233)
Household workforce	0.162* (0.092)	0.417*** (0.105)	0.334*** (0.111)	−0.116 (0.139)	0.039 (0.098)
Household income	−0.015 (0.011)	−0.020 (0.012)	−0.053*** (0.014)	0.057*** (0.013)	0.009 (0.011)
Farm advisory	0.046 (0.255)	0.418 (0.280)	0.809*** (0.293)	0.476 (0.290)	−0.077 (0.262)
Credit service	−0.607** (0.302)	−0.222 (0.320)	−0.068 (0.304)	−0.301 (0.348)	−0.115 (0.305)
Climate information	0.238 (0.216)	−0.059 (0.228)	−0.441* v0.245)	−0.015 (0.263)	−0.387* (0.220)
Social media usage	0.119 (0.219)	−0.087 (0.238)	−0.404* (0.240)	−0.631** (0.300)	−0.472* (0.249)
Constant	−1.221* (0.718)	−0.822 (0.754)	0.597 (0.767)	−7.323 139.549)	0.269 (0.782)
Wald chi2(60)	*234.14*				
Prob > chi2	*0.000*				
Log likelihood	*−524.358*				
Number of observations	*480*				
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2(10) = 79.838 Prob > chi2 = 0.0000					

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ ***, R(SE) = regression coefficient (standard error).

services, 42% of households indicated access to farm advisory services, and 32% mentioned access to credit and microloans by public and private banks in the country. In terms of information access, nearly two-thirds of the sampled households stated access to climate and weather forecasts, and one-third of them reported regular usage of social media, which has become increasingly popular among rural youth during the past few years [16].

4.4. Determinants of households' choices of livelihood adaptation strategies

4.4.1. Age of household head

Our results (Table 2) on the correlation between age and livelihood choices reveal that the age of the household head has positively influenced the adoption of poultry and livestock farming and the initiation of small-scale enterprises. In contrast, it had a negative relation with non-farming jobs and the trade of farm produce. However, the reported relation is not significant. These results imply that rural dwellers of higher age are more inclined towards poultry and livestock farming rather than trade or non-farm jobs. This could either be due to their physical strength, as they might not be able to travel to town often and deal with complex trading operations, or due to their more experience in livestock or poultry rearing, which makes them opt for such livelihood options in the face of climate risks to crop farming. Like our findings, another study [63] also reported a positive association between farmers' age and their tendency towards livelihood adaptation; however, in our case, age did not show a significant relationship.

4.4.2. Education of household head

Education has shown a significant positive relationship with respondents' tendency to shift to off-farm jobs, while it has negatively affected their likelihood of poultry farming. This implies that since household heads with more schooling years are well educated, they find it easy to get a job in the city rather than being farmers as it is becoming riskier. Further, the negative impact on poultry farming might be because they either do not consider this a viable solution to earn enough capital through rearing chickens and ducks, or they simply have other better alternatives to consider earning a livelihood. Our results basically show that education level is a significant determinant of rural people's tendency to diversify their livelihood. These results are supported by the findings reported in South Africa [64], which also show a positive effect of education on farmers' adaptive behavior.

4.4.3. Household size

Household size shows a significant positive effect on rural households' tendency to opt for small enterprises, while it has a significant negative influence on their probability of considering a non-farming occupation in the city. These results imply that with the increase in family members per household, it is more likely that they will start their own businesses. We further asked about the major off-farm ventures and found that the options mostly adopted by rural households are opening a general store, an oil agency, or a small-scale wheat flour unit. A negative association of household volume with finding a job in town shows that since most people are available to work in a family business, they prefer to start their own business rather than move to the city for other jobs.

4.4.4. Landholding

We further found that households' landholding showed a significant negative association with most of the adopted strategies. This is mainly due to the fact that since they own the land, they definitely cultivate it and do farming. Further, many studies have proved that households who own more land are less likely to adopt non-farm livelihood strategies [4,25]. However, interestingly, the results showed a positive association between land size and the likelihood of starting a small business. This is mainly because many influential big farmers also work as traders of agricultural commodities and thus own an *Aarat* in *Ghala Mandi* (a local center for buying and selling farm produce). Therefore, they tend to operate this business in addition to farming. They store the farm produce of their own land and of other farmers in their social circle and sell it for more profit when demand rises.

4.4.5. Land ownership

We further found that households who have ownership rights over the land they toil are less likely to consider poultry, livestock farming, and trading as they showed a significant negative association with land ownership. This is mainly because of their dependence on crop farming as a primary source of family income; thus, they are less likely to opt for other livelihoods. Another reason why tenant farmers have a larger tendency towards such off-farm livelihood strategies is that they do not have many stakes in farming, such as looking after their inherited farmland; thus, it is easier for them to take radical steps of quitting agriculture. Our results contradict another study in KP province in Pakistan [25], reporting a non-significant positive relationship between farmers' land ownership and their off-farm livelihood strategies. The difference could be due to varying climatic conditions and farming systems in both regions.

4.4.6. Irrigation pump ownership

The results revealed that households that possess an agriculture borewell are more likely to consider doing a job in a nearby city as it has shown a significant positive relationship with the availability of irrigation. Apparently, our study does not find any reason why this is the case, as ideally, farmers who have access to irrigation pumps are more likely to be involved in farm-related livelihoods [23,55]. A possible reason for this finding could be a relatively higher financial resilience of these irrigation pump-owning households, as rich farmers can afford to have personal borewells, due to which they do not consider strategies such as poultry or livestock farming, which small-scale subsistence farmers mainly adopt.

4.4.7. Household workforce

The household workforce represents the number of people available to work and contribute to household income. We find that households that have more members working are more likely to obtain livelihood from livestock farming, as it has shown a significant positive correlation. In contrast, the results report a significant negative effect of the household workforce on occupations such as trade, implying that they are less likely to opt for trading if they have more household workforce. This is mainly due to the fact that with more family members available to work in a family business, households are more likely to practice animal husbandry than other businesses as there are more hands to work on a family farm. Another reason why they are less likely to consider trade could be because of a lack of farmland or agricultural machinery such as a tractor. Trade of farm produce is generally possible if a rural household owns essential logistic facilities and storage places such as tractor trolleys, carts, and sheds, which mostly are owned by big landlords; thus, they are less likely to consider such occupations and prefer businesses which require less capital investment and more manual work.

4.4.8. Household income

Our findings depict that rural households who have more monthly income are less likely to adopt trading as a livelihood, as a significant negative correlation has been found. This could be due to their other income sources, such as non-farm jobs (regular monthly salary). That is why they do not rely on farming-related occupations and trading. This could also be a reason that if they have more income, it is probably because of a job in the nearby town, as a job provides a sustainable livelihood source compared to farm-related occupations, which have become highly vulnerable to climate change-induced disaster risks. Previous studies [23,64] also support this argument of higher adaptability to climate disasters among financially well-off households.

4.4.9. Farm advisory

We find that households' access to farm advisory services has positively influenced the adoption of major livelihood strategies. For most strategies, the correlation remains insignificant and positive; however, it has shown a significant positive impact on the adoption of farm produce trade as a livelihood strategy. This shows that households are more likely to consider the trade of cereal grains if they have regular contact with the agricultural extension agent. This is mainly because farm advisors often guide rural communities about various strategies that can raise their household income through farming and related ventures [65]. Further, since climate-induced disaster risks are posing serious threats to rural livelihoods, farm advisory providers are now guiding the communities to find new ways to sustain their livelihood by keeping them updated with buying and selling prices of agricultural commodities. Previous studies also confirm these results, indicating a positive effect of farm advisory services on rural households' adaptation to climate change [16,23,55].

4.4.10. Credit service availability

Credit and loan services provided by financial institutions (banks) play a pivotal role in improving the financial resilience of rural households [66]. It helps them meet sudden fiscal needs in case of natural disasters. This might be the reason that it has shown a negative correlation with livelihood strategies as credit services are mainly provided to the farmers to facilitate their on-farm adaptation strategies (crop-related measures) and, therefore, can mostly be accessed by farmers on the basis of owned farmland. Therefore, farming households access credit services to meet the rising cost of farm inputs [23]. This might be the reason that it has shown a negative correlation with the adoption of all the livelihood strategies, which, by nature, are non-farming strategies. Specifically, a significant negative correlation between credit access and poultry farming is found, which shows that households who access loans from government schemes are more likely to keep practicing agriculture rather than turning to an alternative such as rearing chickens or ducks.

4.4.11. Climate information access

If rural communities have access to accurate forecasts about current and potential weather events or climate disasters, they prepare themselves to cope with unpleasant extreme weather events effectively. This might be the reason that access to climate forecasts has adversely influenced the adoption of most non-farming livelihood strategies. In particular, a significant negative correlation is observed between climate information access and rural households' tendency to consider the trading of farm produce as a livelihood strategy. This means that households are less likely to shift to non-farm livelihoods if they have proper guidance on risk management measures; therefore, they might only be cultivating agricultural crops. In line with our findings, studies in China [63] and Ghana [67] also report that access to climate risk information plays a vital role in increasing farmers' tendency to better cope with the risk posed to their crops.

4.4.12. Social media usage

Given the advancement in telecommunication technologies, rural households, even in the remotest corner of the world, now have access to desired information through mobile devices [43]. Therefore, exposure to social media, in particular, can play a key role in shaping rural dwellers' decisions regarding their livelihood choices. Our results show that household heads who are regular users of social media are less likely to consider small businesses, non-farm jobs, or trade of farm commodities. The reason for this intriguing revelation could be due to households' inclination towards crop farming. As explained earlier, non-farming livelihoods are only adopted if agriculture does not yield the desired outcomes. This means that with social media usage, households might have better access to essential agricultural information related to the adaptation of crops to climatic and induced risks. Therefore, they are able to cope with the risks and continue farming agronomic crops. Our results align with the findings reported in Italy [68], where farmers' access to the Internet appeared to have improved the quality, efficiency, and legitimacy of decision-making regarding agricultural adaptation to climate change.

5. Conclusion and implications

Climate change and induced disasters have posed extreme challenges to various economic sectors around the world. Many developing nations are particularly vulnerable to climate change because of their higher dependence on agriculture and associated sectors. Thus, for rural communities, whose primary income comes from agriculture, this implies that their livelihood is susceptible to climate change. Given this scenario, there is a continuous livelihood transition in many developing countries like Pakistan, where some rural communities are increasingly shifting their livelihood source to non-farming occupations, given the adverse climate impacts on agriculture. This study, therefore, intends to explore the dynamics of transition in terms of exploring rural households' livelihood diversification in the face of climate extremes and analyze the key drivers of this process. For this purpose, a sample of 480 households was drawn from selected sites in Pakistan by using a multistage stage sampling design, and household heads were interviewed face to face. Descriptive and inferential statistics (multivariate probit model) are used to analyze the collected data.

Our results reveal that households reported various livelihood strategies in the face of climate change. Most households reported livestock and poultry farming as major strategies followed by non-farm jobs, trade, small businesses, work as wage laborers, small-scale agriculture value addition, and shift to horticultural crops. The estimates of multivariate probit regression further depict that households' choices of these livelihood strategies are significantly shaped by their socio-economic and related attributes. The regression analysis concludes that education, household workforce, and farm advisory access are the positive drivers of livelihood adaptation. This implies that education and awareness of household heads could play a crucial role in enhancing their livelihood resilience to climate and associated risks. Notably, improved access to agricultural extension services led to a higher adaptation intensity, while higher social media usage adversely affected this tendency.

These findings suggest improvements in rural dwellers' education and awareness about various livelihood strategies. For this purpose, governmental and non-governmental agencies can play a central role in the capacity-building of rural households in terms of improving their basic skills about starting a new business, such as small-scale poultry and dairy farming and small-scale value addition of farm produce, which will boost their earning and hence livelihood resilience. Furthermore, advisory-providing institutions such as the Directorate of Agriculture (Extension) Punjab could play a role in training households on starting small businesses in order to establish a sustainable and climate-resilient livelihood source. Moreover, based on our findings, we suggest monitoring social media platforms that might be spreading misinformation through various channels, as exposure to social media adversely affects rural households' adaptation. For this issue, the Directorate of Agriculture (Information) Punjab can play a role in regulating the accuracy of information rendered to rural households through various ICT-based channels.

This research has some limitations. First, it only focuses on the Punjab province of Pakistan; therefore, the results are not necessarily generalizable to other provinces. However, other regions with similar agroecological and socio-economic features may also benefit from this study to guide their climate adaptation policies for agricultural and rural development. Second, this research used a quantitative approach, which lacked providing an in-depth understanding of the posed risks and adopted measures. Therefore, we suggest future researchers employ a mixed method approach to include a qualitative assessment of perceived risks, their intensity, and useful adaptation strategies by rural communities.

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Ethical statement

This research was conducted with the respondents' consent according to approval guidelines of the ethical review committee, School of Management Science and Engineering, Nanjing University of Information Science and Technology (NUIST), Nanjing 210098, China (NUIST-MSE-22-1698).

CRediT authorship contribution statement

Nasir Abbas Khan: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ashfaq Ahmad Shah:** Writing – review & editing, Supervision, Software, Methodology, Investigation, Formal analysis. **Ataharul Chowdhury:** Writing – review & editing. **Libin Wang:** Writing – review & editing. **Bader Alhafi Alotaibi:** Writing – review & editing, Funding acquisition, Dr. **Muhammad Rafay Muzamil:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28003.

Appendix

Table A1
Distribution of sample and sampling stages

Districts	Sub-districts selected	Union Councils	Villages surveyed	households interviewed
Gujranwala	2	4	8	120
Sheikhupura	2	4	8	120
Nankana Sahib	2	4	8	120
Kasur	2	4	8	120
Total	8	16	32	480

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