Flood Hazards and Livelihood Vulnerability of Flood-Prone Farm Dependent Bait Households in Punjab, Pakistan

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Research Article

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Posted Date: June 23rd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-327153/v1>

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Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on September 18th, 2021. See the published version at <https://doi.org/10.1007/s11356-021-16443-4>.

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Abstract

Pakistan is one of the most climate change and natural disasters affected country of the world where livelihood and lives of inhabitants are often affected due to these disasters. In the scenario of various disasters and risks, flood disasters are the most recurrent hazards that causes *Bait* households livelihood more vulnerable. Hence this research work has focused to investigate livelihood vulnerability of flood-prone *Bait* households in southern Punjab of Pakistan. This study used multistage sampling technique for collection the cross sectional data of 398 flood disasters vulnerable *Bait* household's respondents from three high risks flood-prone districts Muzaffargarh, Rajanpur and Rahim Yar Khan. Face to face interview procedure and well developed pre-tested questionnaire was used for data collection in this research work. This study applied vulnerability framework of LVI-IPCC and LVI in the direction of comparing the level of vulnerabilities in preferred three *Bait* district households. Empirical estimates of LVI major components and framework of IPCC vulnerability have indicated *Bait* households of Muzaffargarh more vulnerable owing to higher exposure and sensitivity and

lower adaptive capacity rather than other districts. In contrast to other districts Muzaffargarh households have investigated more vulnerable to flood disasters more particularly in LVI sub-components such as health (0.460), water (0.360) and food (0.515) access. These research findings will helpful to policymakers to work out and put into practice effectual programs and strategies such as constructing more water reserves, developing overhead infrastructure, easy access of institutional loans and generating off-farm income sources. These local based feasible measures will helpful for native inhabitants to reducing frequency of floods in the direction of lessen vulnerability and increase resilience via recovering generally the livelihood of vulnerable *Bait* households in Punjab Pakistan and particularly the district Muzaffargarh.

Keywords; Flood disasters, Exposure, *Bait* communities, Livelihood vulnerability index, Punjab

1. Introduction

Floods, earthquakes, landslides, cyclones and droughts are some significant natural hazards owing to greater than before incidence of excessive climate change (Toe et al., 2018; Eckstein et al., 2019; Ahmad et al., 2019; Elahi et al., 2021). In current global scenario, floods are considered the most consecutive and more destructive rather than other hazards (Toe et al., 2018; Ahmad et al., 2019; Al Baky et al., 2020; Hoq et al., 2021) the reason of considerable involvement to social risk, economic losses and human fatalities as mainly exposed by human (Abbas et al., 2017; Huong et al., 2019; Ahmad and Afzal, 2021). These natural disasters affected more than 96 million peoples throughout the world in 2017 in which majority population 60% was affected from flood hazards (World Bank, 2013; Emergency Event Database (EEDAT), 2017; Eckstein et al., 2019). In the current couple of decades, rising recurrence and severity of floods have estimated more particularly in South Asian and South East Asian countries (Krausmann and Mushtaq, 2008; Hirabayashi et al., 2013; Toe et al., 2018; Hussin et al., 2019) where some Asian countries India, China, Bangladesh and

62 Pakistan are indicated as supermarkets of flood disasters (James, 2008; Abid et al., 2016; Ahmad et al., 2019). Scarce resources,
63 inadequate infrastructure and limited flood adaptive mitigation measures are significant factors of increasing flood vulnerability
64 (Daniell et al., 2016; Abbas et al., 2017) mostly for rural community in developing countries (Zhang et al., 2011; Abid et al., 2016).
65 More particularly in developing countries, anthropogenic factors such as human encroachment in rivers coupled with environmental
66 and climatic change have played major role to increasing flood hazards (Gaurav et al., 2011; Toe et al., 2018).

67 In the global scenario, Pakistan indicated as world 5th most natural hazards affected country (Eckstein et al., 2019) due to specifically
68 located in hazards prone region and facing frequent floods (Abbas et al., 2017; Ahmad and Afzal, 2021). Glacier melting, erratic rains
69 and expanding cycle of monsoon rainfalls are significant factors correlated to consecutive floods in interlined rivers concerning
70 upstream or downstream rivers (Teo et al., 2018; Ahmad et al., 2020). In scenario of natural hazards as more specifically the flood
71 hazards, Pakistan faced the worst flood disaster of history in 2010, which caused cumulative economic cost of 10 billion US dollars,
72 destroy cropped area of two million hectares and twenty-four million peoples were adversely affected (Rafique and Blaschke, 2012;
73 United Nations, 2011; Khan, 2011; Abid et al., 2016).

74 In the last couple of decades, inhabitants of Punjab province of Pakistan pragmatic climate based drastic changes including the more
75 significant and affecting factors such as evident precipitation, grain production changes, weather pattern alteration, droughts, floods
76 and weather pattern shifting (BOS Punjab, 2017). In Punjab, climate vulnerability mostly contributed by various sectors such as
77 urbanization, industrialization, agriculture, transportation, waste and energy which directly rises the Green House Gases emission
78 (Hussain et al., 2019). An increasing scenario of atmospheric pollution in Punjab is the reason of incompetency and inconsistencies
79 about the understanding the geography, climate and production factors (Qayyum et al., 2016; Hussain et al., 2019). In the last, three
80 decades, mean temperature of climate warning trend observed in the range of 0.78 °C to 1.5 °C which is predictable to increase 2 °C to
81 4 °C (Rasul et al., 2012; IPCC, 2014; Abbas et al., 2017; Bokhari et al., 2018) and such dramatic rise in temperature severely affect
82 agricultural production of Punjab province (Abbas et al., 2017; Amin et al., 2018; Tariq et al., 2018). Events of extreme temperature,

83 droughts and floods are some significant climate related risks which negatively affects farming system and livelihood through water
84 shortage and crop yield losses (Gorst et al., 2018; Ahmad and Afzal, 2020). More specifically in current few years climate change
85 caused severe losses of staple crops such as wheat production declined 2.26% in 2017, 4.4% in 2018 and in early quarter of 2019
86 unexpected weather conditions as hailstorms, windstorms and heavy rains caused significant losses to standing wheat crop. Punjab
87 province area consists of fertile lands, categorized as arid land in southern region whereas semi arid in central region and precipitation
88 occurs in monsoon season from month of July to August (Mehmood et al., 2016; Abbas et al., 2017).

89 Punjab is officially recognized the land of five rivers Chenab, Jehlum, Ravi, Indus and Sutlej (Pakistan Bureau of Statistics (PBS),
90 2019). Chenab and Indus are major rivers of Pakistan (Ahmad et al., 2021) more prominently causes severe floods destructions
91 specifically in summer season (UNDP, 2019). In flowing process, these rivers naturally dispersed in different temporary channels
92 when passing through various areas as temporary islands are usually generated within the area of river. In the region of southern
93 Punjab, these temporary islands within the rivers in local language Saraiki are formally known as *Bait*¹, areas. Local community
94 particularly inhabited in the neighbouring of these rivers usually settle and performs their farming practices in these islands and mostly
95 cultivate such *Bait* areas. In flooding season, these Bait areas are in a straight line under fire by rivers. In floods and rainy season these
96 communities have to undergo severe losses of livestock, crops, human fatalities, damages of infrastructure and destruction of houses.
97 Southern Punjab region in Punjab province is higher vulnerable of flooding due to side by side flowing of Chenab and Indus rivers
98 (PDMA, 2017). Livelihood status of *Bait* farming community adversely affected due to consecutive occurrence of floods rather than
99 farming community from rest of the region, province or country. Southern Punjab *Bait* household inhabitants of Pakistan are higher
100 vulnerable to flood hazards due to using inadequate measure of mitigation to overcoming these natural disasters risks. Inadequate
101 communication and awareness sources, limited role of disaster institutions, and lack of resources allocation to hazards mitigation
102 measures major factors to increasing vulnerabilities of *Bait* inhabitants (Singh and Sagar, 2012; Ahmad and Afzal, 2021).

¹ Temporary islands are usually generated within the area of river in local language Saraiki are formally known as *Bait*

103 In literature, some studies of developed and developing countries specifically considered the aspect of flood risks adaptation (Birkholz
104 et al., 2014; Lopez-Marrero and Yarnal, 2010), constraints and choice of mitigation of floods (Paul and Routray, 2010; Wisner et al.,
105 2004), flood risk management (Wilby and Keenan, 2012; Osberghaus, 2015) and livelihood vulnerability to flood hazards (Hoq *et al.*,
106 2021). In Pakistan for the most part of flood hazards literature determined the aspect of flood hazards management and assessment
107 (Hashmi et al., 2012; Bahadar et al., 2015; Tariq and Van De Giesen, 2012), flood hazards perception and adaptation strategies
108 (Ahmad and Afzal, 2020; Ahmad et al., 2020), floods causes, consequence and protection measures (Yaqub et al., 2015; Khan, 2011),
109 riverbank erosion and inundation of hazards zone (Khan et al., 2017; Ali and De Boer, 2010), riverbank erosion and protection work
110 (Ashraf and Shakir, 2018; Khan and Ali, 2003), some studies focused the aspect of adaptation level and local mitigation measures
111 about affects of post floods (Abbas et al., 2017; Abid et al., 2016). In Pakistan, limited research specifically firmed the aspect of flood
112 hazards affect of food security and poverty (Ali and Rahut, 2020; Ashraf and Shakir, 2018), flood hazards resilience (Ahmad et al.,
113 2019), flood persuaded vulnerability and risks of health (Shah et al., 2020), and gender based aspect of flood hazards adaptation
114 strategies (Ahmad et al., 2021).

115 In the above mentioned available literature, the aspect of flood hazards, livelihood vulnerability of flood-prone farm dependent
116 household's poorly addressed in global scenario whereas according the best knowledge of author this aspect not appropriately
117 addressed in developing countries particularly to Pakistan where agriculture sector is badly affected due to severe natural disasters like
118 floods. To address such research gap in specific scenario of Pakistan this study focused to highlight the flood hazards, livelihood
119 vulnerability of flood-prone farm dependent households *Bait* communities in Punjab, Pakistan. Objective of this research work is to
120 examine the flood hazards and livelihood vulnerability of flood-prone farm dependent households *Bait* communities in Punjab,
121 Pakistan. There is some significance of this study in scenario of Pakistan, firstly no research work in this area tried to explore the
122 aspect of Bait community flood hazards livelihood vulnerability in literature as this study tried to focus this aspect. Secondly, no study
123 in Pakistan has used Livelihood Vulnerability Index (LVI) all indicators for vulnerability estimation as this research work carried out
124 to explore the vulnerability of Bait community household through all indicator of LVI also through LVI and IPCC components. This

research is classified in to five sections, introduction elaborated in first section, data and methodology explained in second section and third section highlighted the empirical results of the study. In section four discussions is indicated whereas last section of the study illustrated conclusion and suggestion.

2. Data and methodology

2.1 Rationalization of study area selection

In four provinces of Pakistan, Punjab was selected for this study owing to few significant reasons. Firstly, Punjab shares 52.95% population, 26% area and supply 53% agricultural GDP of the country (PBS, 2017). Secondly, Punjab among four provinces is higher vulnerable of floods hazards due to consecutive flowing of five rivers throughout the fertile lands of province (PDMA, Punjab 2017). Thirdly, southern Punjab region more particularly selected for study the reason of located both sides of Pakistan's largest river Indus and consecutively facing flood disasters (BOS, 2017; NDMA, 2018). Fourthly, in region of southern Punjab *Bait* communities inhabited in the temporary island due to riverine distributor channels of Indus River and engaged farming practices, more vulnerable of flood hazards specifically focused for this study. Lastly, based on mostly flood risk seven districts *Bait* communities of Punjab, higher flood risk disasters vulnerable three district Muzaffargarh, Rajanpur and Rahim Yar Khan *Bait* communities were (PDMA, Punjab 2014) more preferably selected for the study.

[Figure 1]

2.2 Study area geographical features

Muzaffargarh district consists four tehsils (sub-district in district area) Kot addu, Jatoi, Alipur, Muzaffargarh and 93 union councils (Pakistan fifth administrative unit and local government second tier) (Government of Pakistan (GOP), 2020) with area of 8249 km² and population of 4,322, 009 (PBS, 2017). Muzaffargarh district consider higher vulnerable to consecutive flood disaster owing to located in critical geographical scenario surrounded by two major rivers as Indus flows western side while Chenab flows eastern side

145 of district (Bureau of Statistics (BOS) Punjab, 2019). Mild winter and hot summer, average rainfall of 127mm with highest 54°C
146 (129°F) and lowest 1°C (30°F) temperature are some significant feathers of this area (Pakistan Metrological Department (PMD),
147 2019). In the couple of decades, this district faced erratic rainfall and frequent floods those caused foremost losses of infrastructure,
148 crops, livestock and human fatalities (PDMA Punjab, 2014) and due to lowest social progress index and cultural, social and economic
149 dimensions indicated as lower socioeconomic status district (BOS Punjab, 2019).

150 [Figure 2]

151 Rahim Yar Khan district administratively divided in to four tehsils (sub-district in district area) Khanpur, Liaquatpur, Sadiqabad and
152 Rahim Yar Khan (GOP, 2020) by area of 11,880 km² and population of 4,814, 006 (PBS, 2017) higher vulnerable due to extreme
153 flood disasters as located on eastern bank of river Indus (PDMA Punjab, 2014). In scenario of long and extreme summer Rahim Yar
154 Khan regarded as hot region with average temperature 26.2°C in this area (PMD, 2019). Majority population (65%) of district
155 affiliated with agriculture (BOS Punjab, 2019) whereas during the current couple of decades because of climate change having sever
156 issues of excessive flood hazards and confronted with losses of infrastructure, livestock, crops and human fatalities (PDMA, 2014).
157 District Rajanpur covers the area of 12,318 km² and consists population of 1,995,958 and administratively divided in to three tehsils
158 (sub-district in district area) Jampur, Rojhan and Rajanpur (BOS Punjab, 2019). Long and extreme summer in district Rajanpur
159 indicated region hot weather which frequently stuck strongly excessive flooding with major destruction of infrastructure, crops and
160 human fatalities due to situated on the western bank of Indus River (PBS, 2017).

161 These three districts share some diverse and common demographic and socioeconomic feathers which play significant role on
162 livelihood vulnerability of flood-prone farm dependent Bait households in Punjab, Pakistan. In these three districts some minor
163 variation in family average size was indicated from 9 to 11 members (PBS, 2017) whereas some significant variation regarding land
164 holding average size among these study districts indicated as lower land holding average size in Muzaffargarh (4.4 acres) as compared
165 to Rahim Yar Khan (6.4 acres) and Rajanpur (5.4 acres) (PBS, 2010; BOS Punjab, 2017) Some variation in agricultural income

166 significance in total income was estimated among three districts as higher importance of agricultural income was in Rahim Yar Khan
167 (85%) rather than Rajanpur (74%) and Muzaffargarh (69%) (Nazli et al., 2012; Abid et al., 2016; BOS, Punjab 2018).

168 2.3 Sampling technique and data collection

169 Multistage sampling technique was used in this study for data collection, firstly based on higher vulnerability of floods destruction
170 Punjab among four provinces preferred for this study (PDMA, 2014). Secondly, *Bait* communities of southern Punjab region because
171 of higher vulnerability and consecutive flooding specifically focused for this study. Thirdly, out of seven riverine *Bait* communities'
172 districts of province, three higher risk flood hazards vulnerable districts Rajanpur, Rahim Yar Khan and Muzaffargarh (PDMA
173 Punjab, 2017; National Disaster Management Authority (NDMA), 2018) *Bait* communities were particularly selected for the study.
174 Fourthly, two tehsils from each district and two union councils each tehsil were purposively chosen on the basis of flood vulnerability
175 according to list provided from District Disaster Management Authority (DDMA), local land record officer (patwari) and agriculture
176 officer. Lastly, two *Bait* community villages from each union council were selected based on higher flood destruction and
177 vulnerability and sixteen farmer's respondents from each village were randomly selected and were interviewed.

178 In data collection households indicated basic unit and head of household (female/male) considered major respondents of this study
179 area. For attaining sample size minimum level, this study employed Cochran (1977) sampling method as elaborated in equation 1.
180 Household heads were specifically targeted for data collection of 398 respondents and population of 5% indicated sufficient (Kotrlik
181 and Higgins, 2001). In equation (1) sample size indicated as SS, confidence level elaborated as $Z (\pm 1.96 \text{ at } 95\%)$ for picking points
182 percentage choices as p , as decimal explained (0.5 employed required sample size) and value of precision was indicated as $e(0.07 = \pm$
183 $7)$.

$$184 \quad \text{Sample Size} = \frac{Z^2(p)(1-p)}{e^2} \quad (1)$$

185 Direct respondent's interaction and well developed questionnaire was used for data collection from February to May 2019. In finding
186 adequacy and accuracy of information moreover avoiding ambiguity, questionnaire was used for pilot study and pre-tested through 20
187 respondents prior to proper survey. Five trained enumerators and author himself corrected as well as clarified all relevant issues
188 regarding questionnaire prior starting survey in the study area. In data collection, all respondents were clearly informed about the
189 purpose and use of data and those respondents hesitated to sharing their information was replaced to others.

190 2.4 Analytical technique

191 2.4.1 Vulnerability understanding

192 In research scenario, IPCC² definition standard structure is measured more influential methodical tool for assessment of vulnerability
193 (IPCC, 2001). Numerous scholars in their research studies (Shah et al., 2013; Can et al., 2013; Panthi et al., 2016; Tewari and
194 Bhowmick, 2014; Tjoe, 2016) particularly used the framework of 'indicator based assessment of vulnerability' in different
195 perspectives developed by Hahn et al., (2009). In all major and sub-components based composite index of LVI³ was developed by
196 Hahn et al., (2009) whereas the vulnerability index of IPCC (LVI-IPCC) altogether major components in the three causative factors
197 adaptive capacity, sensitivity and exposure (IPCC, 2001; Hoq et al., 2021). LVI-IPCC and LVI indicators are useful for local policy
198 makers and development organizations to recognize social, demographic and other associated factors so as to put in vulnerability of
199 climate change at regional or community levels. Some studies indicated the less significance the scenario of how extreme events in
200 future alter human systems of adaptive capacity and sensitivity whereas more properly focused the factors of extreme events that
201 increases vulnerability to climate events and extreme weather (Adger, 2006; IPCC, 2014). In accessing the vulnerability this study

² Intergovernmental Panel on Climate Change

³ Livelihood vulnerability index

202 used two analysis sets firstly employing the method of balance weight average for LVI calculation, secondly using framework of
203 IPCC (LVI-IPCC) accessing LVI calculation.

204 2.4.2 Method of balance weight average for LVI calculation

205 In calculating vulnerability level in *Bait* areas of Punjab this research work applied the methodology of Shah et al., (2013), Hahn et al.,
206 (2009) and Hoq et al., (2021). In adopting according to the scenario of the study area some method modifications were made (Huong
207 et al., 2019; Hoq et al., 2021). In analysis procedure, along with to seven components of LVI developed indices (Hahn et al., 2009)
208 two more important components production and housing means (Huong et al., 2019; Sarker et al., 2019) were integrated. In the
209 approach of Hahn et al., (2009) climate variability and natural disasters considered single major components whereas this research
210 work considered it as two major components one by one in consistency with Sarker et al., (2019). In this study for computing in LVI,
211 fifty-one sub-components and nine major components as indicators for livelihood were employed as indicated in table 1. Each major
212 component contribution is diverse sub-component indicators in this approach and each major or sub component contributing equally
213 in overall LVI (Sullivan et al., 2002; Hoq et al., 2021). Livelihood strategies (LS), socio-demographic profile (SD), water (W), foods
214 (F), health (H), social network (SN), natural disasters (ND), production and housing means (PHM), climate variability (CV) indicated
215 major components of this study. In calculate index of life expectancy that is difference ratio in actual and pre-selected minimum life
216 expectancy and predetermined range of minimum and maximum life expectancy Human Development Index (HDI) formally
217 employed as indicated in equation (2) (United Nation Development Programme (UNDP), 2007). The each sub-component index was
218 expressed in equation 2 as given below

$$219 \quad Index_{scd} = \frac{SC_d - SC_{min}}{SC_{max} - SC_{min}} \quad (2)$$

220 The each sub-component or indicator standardized value indicated as $Index_{scd}$, district (d) sub-component actual or original value
221 highlighted as sc_d , as each sub-component maximum value sc_{max} and minimum vale sc_{min} as elaborated in equation 2. In particular,

measuring variable frequencies like household percentage, coverage enquiry about community based water resources conflicts as given maximum value 100 and minimum 0. Following the logic minimum and maximum values were transformed and these sub-components were standardized in equation 2. Subsequently to each sub-component standardization calculation of every major component was made through n number of sub-component averaging by employing equation 3.

$$MC_d = \frac{\sum_{i=1}^n Index_{scdi}}{n} \quad (3)$$

In nine major components, one indicated as MC_d and d as district, sub-component index as $Index_{scdi}$, n and i indicate sub-component numbers in every major component. In equation 4, each district all major component values were calculated as LVI district level taken by averaging all major components in every district.

$$LVI_d = \frac{\sum_{i=1}^n w_{MCdi} MC_{di}}{\sum_{i=1}^n w_{MCdi}} \quad (4)$$

The notion of LVI_d , was indicated as LVI for the d district, and equivalent to nine major components average weighted. w_{MCdi} explained as each major component weight as calculated through sub-components numbers and incorporated to make sure that contribution of all sub-components equivalently on the whole LVI (Sullivan et al., 2002) as equation 4 expressed and indicated in equation 5, such in which LVI scaled most vulnerable as 0.5 and least vulnerable as 0.

$$LVI_d = \frac{W_{SD}SD_d + W_{LS}LS_d + W_{SN}SN_d + W_F F_d + W_H H_d + W_W W_d + W_{HPM}HPM_d + W_{ND}ND_d + W_{CV}CV_d}{W_{SD} + W_{LS} + W_{SN} + W_F + W_H + W_W + W_{HPM} + W_{ND} + W_{CV}} \quad (5)$$

2.4.3 LVI calculation based on framework of IPCC (LVI-IPCC)

Vulnerability consider the function based on sensitivity, adaptive capacity and exposure about hazards according to IPCC, (2007) as explained below

$$\text{Vulnerability} = f(\text{exposure}, \text{sensitivity}, \text{adaptive capacity})$$

Such investigation related to vulnerability theories indicating as due to low adaptive capacity households are specifically vulnerable (Adger, 2006; IPCC, 2007; Hoq et al., 2021). Exposure reports, specific location or environment of people influenced harmfully via physical events as in this manner focus to possible future damages, harm or loss (Gasper, 2010). Sensitivity mentions degree to that system is affected due to exposure whereas system's capacity to recover from exposure indicated as adaptive capacity (Ebi et al., 2006). There are various indicators composes to exposure, sensitivity and adaptive capacity. In the current era, numerous studies in world scenario employed index based method for vulnerability measurement (Shah et al., 2013; Gasper, 2010; Hahn et al., 2009; Toufique and Islam, 2014; Aryal et al., 2014). On the basis of equation 6, IPCC three factors adaptive capacity, exposure and sensitivity were deliberated.

$$CF_d = \frac{\sum_{i=1}^n w_{MCdi} MC_{di}}{\sum_{i=1}^n w_{MCdi}} \quad (6)$$

Adaptive capacity, exposure and sensitivity as three contributing factors of IPCC indicated as CF_d , whereas d explains district, district d major component elaborated as MC_{di} , while major components weights explained as w_{MCdi} , and each contributors factors of major component numbers shown as n. In equation 7, exposure index was expressed with relevant two contributing factors as climate variability (CV) and natural disaster (ND)

$$Index(Exp)_d = \frac{W_{exp1} ND + W_{exp2} CV}{W_{exp1} + W_{exp2}} \quad (7)$$

In equation 7, district based exposure index indicated as $Index(Exp)_d$, whereas major components climate variability and natural disasters weights were expressed such as W_{exp2} , W_{exp1} . Water (W), health (H), food (F) and production and housing means (PHM) indicated major contributing factors of sensitivity for d districts as sensitivity index was expressed in equation 8.

$$Index(sen)_d = \frac{W_{sen1}F + W_{sen2}H + W_{sen3}W + W_{sen4}HPM}{W_{sen1} + W_{sen2} + W_{sen3} + W_{sen4}} \quad (8)$$

Major components of production and housing means, water, health and foods weights were reported as W_{sen1} , W_{sen2} , W_{sen3} and W_{sen4} as highlighted in equation 8. In equation 9, socio-demographic factors (SD), livelihood strategies (LS) and social network (SN) were elaborated contributing factors of adaptive strategies index.

$$Index(adapt)_d = \frac{W_{adapt1}SD + W_{adapt2}LS + W_{adapt3}SN}{W_{adapt1} + W_{adapt2} + W_{adapt3}} \quad (9)$$

These major components livelihood strategies, social network and socio-demographic are three contributing factors weights were expressed as such W_{sen1} , W_{sen2} and W_{sen3} . Subsequently once calculating these three livelihood strategies, social network and socio-demographic contributing factors these were combined in equation 10.

$$LVI - IPCC_d = [Index(sen)_d - Index(adpt)_d] * Index(exp)_d \quad (10)$$

In using vulnerability framework of IPCC the LVI-IPCC was reported for LVI and district denoted for d, exposure calculated score for district d as $Index(exp)_d$, sensitivity for district d calculated score as $Index(sen)_d$, and adaptive capacity for district d calculated score as $Index(adpt)_d$. In LVI-IPCC were reported as scaled for most vulnerable +1 and least vulnerable -1.

3. Empirical results

In LVI contributing factors of IPCC (sensitivity, exposure, adaptive capacity), major components (climate variability, natural disasters, food, water, health, production and housing means, livelihood strategies, social demographic factors, social network) and subcomponents, explanation, citation and expected association as indicated in table1.

[Table 1]

274 Three districts livelihood vulnerability unit measurement, maximum, minimum and actual values of subcomponents elaborated in
275 table 2 whereas normalized sub-components and major components livelihood vulnerability indices of three districts explained in table
276 3. Contributing factors of IPCC and values of major factors are indicated in table 4 while major components indicated in spider figure
277 3 and LVI contributing factors triangle of three districts also highlighted in figure 4.

278 3.1 Influences of sub-components and major components on overall LVI of the Bait household among the districts

279 Three districts each sub-component livelihood vulnerability indices minimum, maximum and actual values are illustrated in table 2.
280 Muzaffargarh *Bait* community have to travel (178.91 min) average time which is more than Rajanpur (169.87 min) and Rahim Yar
281 Khan (154.01 min) *Bait* communities for health access as indicated in table 2. Access of latrine indicated significant sub-component of
282 health as highlighting *Bait* communities' socioeconomic conditions as limited number of household in Rahim Yar Khan (31%)
283 Rajanpur (39%) and Muzaffargarh (43%) have access of sanitary latrine showing vulnerable scenario as elaborated in table 2.
284 Muzaffargarh *Bait* community (3.4 month) have to struggle more for access sufficient food rather than Rajanpur (3.1 month) and
285 Rahim Yar Khan (2.3 month) indicating higher vulnerable scenario of sufficient food access. Majority community in Muzaffargarh
286 (89%) worried about sufficient food rather than Rajanpur (83%) and Rahim Yar Khan (78%) whereas average index of diversifying
287 crop (0.48) similar in three districts explained in table 2.

288 [Table 2]

289 In Muzaffargarh (27%) *Bait* community having higher conflicts of water in community rather than Rajanpur (24%) and Rahim Yar
290 Khan (19%). Higher proportion of Muzaffargarh (31%) community use unsafe water rather than Rajanpur (28%) and Rahim Yar Khan
291 (23%) and have to travel 5.7 minutes, 4.9 minutes and 3.8 minutes to access safe water as indicated in table 2. Majority of *Bait*
292 communities in Muzaffargarh (68%), Rajanpur (67%) and Rahim Yar Khan (66%) have access of own tubewell for water.

293 3.2 Overall inter-districts households sub-components and major components Livelihood Vulnerability indices (LVI)

294 In table 3 major components vulnerability indices ranged 0.158 to 0.760 as these indices were compared among *Bait* communities of
295 three study areas districts. In district based vulnerability scenario, Muzaffargarh was indicated higher vulnerable for climate variability
296 (0.635), natural disasters (0.501), food (0.515), health (0.460), production and housing means (0.760), livelihood strategy (0.403) and
297 social network (0.424) whereas lower level of vulnerability estimated regarding the social demographic (0.158) and water (0.360) as
298 results are same with the studies of Shah et al., (2013), Hussain et al., (2019), Elahi et al., (2021) and Hoq et al., (2021). In reviewing
299 major components in scenario of sub-components Muzaffargarh district consider higher vulnerable regarding in last 10 years,
300 gradually facing increasing summer duration (0.890), increasing rainfall (0.830) and temperature (0.880), flood events in last ten years
301 (0.816), food primarily from own farm (0.910), worried about insufficient food (0.890), during illness local doctor treatment access
302 (0.960), without solid structure house (0.920), affected floods households (0.950) and agriculture major dependency (0.940)
303 elaborated in table 3. Muzaffargarh geographical conditions such as riverine floods on both eastern (Chenab River) and western side
304 (Indus River) of district caused its higher vulnerability rather than other districts (Abid et al., 2016; PDMA, 2017; Ahmad et al.,
305 2021).

306 *Bait* communities of district Rajanpur regarding to major components were higher vulnerable on climate variability (0.602),
307 production and housing means (0.737) and food (0.490) whereas lower vulnerable to social demographic factors (0.174) and water
308 (0.337) as illustrated in table 3. In the scenario of sub-components Rajanpur *Bait* community was highly vulnerable to increasing
309 summer duration (0.860), increasing temperature (0.830), food from own farm (0.890), insufficient food (0.830), local doctor access
310 (0.930), household solid structure (0.890), flood affects (0.940) and agriculture major income source (0.930) whereas lower vulnerable
311 to safe water access (0.157), missing working days due to illness (0.160) and local organization participation (0.140). In the scenario
312 of vulnerability regarding major components and sub-components almost same trends were estimated in district Rahim Yar Khan as in
313 Rajanpur district as indicated in table 3. In these three districts study areas, riverine floods severity causes' higher destruction of
314 agriculture as threaten the major livelihood source of *Bait* inhabitant's households. Estimates of major components lowest and highest
315 vulnerability are almost similar with the studies of Shah et al., (2013), Abid et al., (2016), Abbas et al., (2017) and Hoq et al., (2021).

[Table 3]

Livelihood Vulnerability Index nine major components aggregate weighted scores indicated as flood hazards caused Muzaffargarh (0.471) most vulnerable rather than Rahim Yar Khan (0.430) and Rajanpur (0.452) districts. In the scenario of socio-demographic factors Rahim Yar Khan (0.176) is higher vulnerable rather than Muzaffargarh (0.158) and Rajanpur (0.174) as indicated in table 3. In livelihood strategy major components, Rahim Yar Khan (0.419) and Rajanpur (0.427) communities were higher vulnerable than Muzaffargarh *Bait* inhabitants (0.403). In major component of health, Muzaffargarh (0.460) and Rajanpur (0.414) *Bait* communities were higher vulnerable than Rahim Yar Khan (0.365) *Bait* community as these findings are in line with the studies of Hussain et al., (2019) and Ahmad and Afzal, (2020).

In table 3, higher score of food vulnerability subsequent to combining food sub-components was estimated in Muzaffargarh (0.515) rather than Rahim Yar Khan (0.438) and Rajanpur (0.490). In Muzaffargarh (0.360) higher vulnerability regarding water was estimated in contrast to Rajanpur (0.337) and Rahim Yar Khan (0.303). In the scenario of production and housing means and flood hazards regarding major components as combination of sub-components Muzaffargarh (0.760) (0.501) and Rajanpur (0.737) (0.444) districts are higher vulnerable rather than Rahim Yar Khan (0.650) (0.386) as indicated in table 3. *Bait* communities of these three districts more vulnerable to natural disaster specifically riverine floods no access of disasters warning, faced consecutive death and injuries and water logging till many months as elaborated in table 3 as these finding are alike to studies of Ahmad et al., (2019), Hussain et al., (2019), Ahmad and Afzal, (2020) and Hoq et al., (2021). Climate variability major components scores were higher among these three districts while Muzaffargarh (0.635) indicated higher vulnerable rather than Rajanpur (0.602) and Rahim Yar Khan (0.595). Major components combined LVI scores estimates are reported in figure 3 spider diagram

[Figure 3]

In figure 3, spider diagram scale ranges 0.7 as more vulnerable while from 0 to less vulnerable scenario. Muzaffargarh district *Bait* community higher vulnerable in climate variability, natural disasters, food, health, production and housing means and water, Rajanpur

337 districts more vulnerable in livelihood strategy whereas Rahim Yar Khan districts higher vulnerable in social networks and socio
338 demographic factors as illustrated in figure 3.

339 3.3 Vulnerability assessment through LVI-IPCC approach

340 The IPCC weighted score of contributing factors sensitivity, exposure, and adaptive capacity and overall LVI-IPCC are illustrated in
341 table 4. Vulnerability estimates indicated district Muzaffargarh (0.087) and Rajanpur (0.079) communities higher vulnerable rather
342 than Rahim Yar Khan (0.038). Economic activates and geographical hazards prone locations are significant factors to increasing
343 adaptive capacity and exposure of community. The lower adaptive capacity of Muzaffargarh (0.328) and Rajanpur (0.343) rather than
344 Rahim Yar Khan (0.362) is major cause of higher vulnerability in these both districts as these findings are similar with the studies of
345 Abbas et al., (2017), Hussain et al., (2019), Ahmad and Afzal, (2020) and Hoq et al., (2021). *Bait* community of district Muzaffargarh
346 higher exposure (0.568) of flood hazards and more sensitive (0.524) rather than other two districts more vulnerable among three
347 districts. District Rahim Yar Khan lower exposure (0.491), sensitivity (0.439) and relatively higher adaptive capacity (0.362) made it
348 less vulnerable rather than two districts. Rajanpur district due to higher intensity based on exposure (0.523), sensitivity (0.495) and
349 lower adaptive capacity (0.343) higher vulnerable rather than Rahim Yar Khan district as indicated table 4 as these findings are similar
350 with the studies of Ahmad and Afzal., (2020) and Elahi et al., (2021).

351 [Table 4]

352 IPCC scores of contributing factors sensitivity, exposure and adaptive capacity illustrated in triangle figure 4 as ranging to higher
353 contributing factors 0.5 and lower contributing factors 0. Bait households of district Muzaffargarh more sensitive (0.524) and exposed
354 (0.568) to climate variability, climate change and floods disasters as lower adaptive capacity caused higher vulnerable rather than
355 other two districts as elaborated in triangle figure 4.

356 [Figure 4]

4. Discussion

In measuring *Bait* households vulnerabilities about climate change, climate driven natural hazards and flood disasters, this research work used major components, related indicators of LVI and contributing factors (adaptive capacity, sensitivity, exposure) of IPCC. For proper understanding the influence of these indicators and components about livelihood vulnerability is crucial (Tran et al., 2020; Hahn et al., 2009) for applying adaptation strategies, coping climate variability and future research for developing countries more specific like Pakistan (Ahmad et al., 2021). Estimates of the study indicated some minimal similarities and some significant vulnerability difference among these three *Bait* community districts study areas have specifically highlighted.

Some significant vulnerability differences among districts are indicated as firstly according to estimates of both LVI-IPCC and overall LVI, Muzaffargarh rather than other two districts indicated most vulnerable district due to facing consecutive riverine floods from western side Indus river and eastern side Chenab river. These both neighbouring rivers causes to increase vulnerability of this area as major destruction of agriculture crops specifically cotton crop, losses of livestock and available infrastructure as communities' livelihood becomes more vulnerable as similar liking indicated in literature studies Sujakhu et al., (2019) and Ahmad et al., (2021). Secondly vulnerability difference among districts is health services access indicated as significant indicator about livelihood vulnerability whereas Muzaffargarh and Rajanpur districts are higher vulnerable due to limited health services access as illustrated with consistent trends of literature (Alam et al., 2017). The reason is that *Bait* communities of Muzaffargarh and Rajanpur districts have limited access of treatment from certified doctors due far areas from main city whereas Rahim Yar Khan *Bait* community higher access to certified doctors treatment due to located neighbouring of main city so location advantage causes the access of health services as findings shows same trends regarding literature Hussain et al., (2019) and Elahi et al., (2021). Thirdly, *Bait* community of district Muzaffargarh in contrast to other districts more involved in chronic diseases and illness and have to leave their work in last two weeks the reason of inadequate advanced health treatment facilities. These results illustrated the same development alike with literature Etwire et al., (2013), Ahmad and Afzal, (2020), and Hoq et al., (2021). Lastly, in contrast to other districts, higher food

378 vulnerability indicated in Muzaffargarh *Bait* community to find food, inhabitants have to struggles almost 3.4 month causes worry to
379 sufficient food as these results illustrated the similar leaning regarding the literature Panthi et al., (2016), Abid et al., (2016) and
380 Hussain et al., (2019).

381 Estimates of the study indicated some significant similarities among three districts firstly higher vulnerable scenario among three
382 districts was indicated regarding component of social network. The reason is of limited access and participation to community based
383 and social organizations such as political or farmers' organizations as these trends are related to literature Abid et al., (2016), Abbas et
384 al., (2017) and Ahmad et al., (2019). Active participation in social structure is prerequisite to minimize vulnerability and boost up
385 adaptive capacity of farming community (Agrawal, 2010). Secondly, among these districts is low literacy rate which causes to less
386 awareness; limited information and limited earning due to inadequate education consider major factors of higher vulnerability in these
387 communities (Ahmad et al., 2021). Thirdly, in these three districts *Bait* communities almost 67% households have no sanitary toilets
388 as causes to increase health vulnerability that is because of river erosion, floods, land scarcity, inadequate roads networks and standing
389 water bodies as findings have same tendency with literature Sujakhu et al., (2019). Fourthly, these three districts have same crop
390 diversity index as apparent from food components thus limited number of *Bait* households engaged homestead, gardening, seed
391 storage and food management practice which causes to increase vulnerability among *Bait* communities' households as estimates same
392 liking with literature Ahmad et al., (2019) and Elahi et al., (2021). Lastly, among districts majority of *Bait* households due to lack of
393 money and inadequate building material higher vulnerable to flood hazards and monsoon rain as their houses become fully or partially
394 damage which causes to poor shelter and overall lower living. *Bait* households also reported as during couple of decades, due to
395 consecutive flood hazards and erratic monsoon badly destructed their farming and fishery as these findings showed similar liking with
396 literature Hussain et al., (2019), Ahmad and Afzal, (2020) and Elahi et al., (2021).

397 Households those engaged in off-farm activities moving outside *Bait* areas for earning and generating external income sources
398 becomes less vulnerable to these hazards as these inclination similar with the literature Nhacolo et al., (2006), Islam et al., (2011),

399 Sujakhu et al., (2019) and Hoq et al., (2021). In some limited measures of water storages from Pakistan's government caused at some
400 extent decrease vulnerability of *Bait* communities as they become less vulnerable to flood disasters as compared to previous decades
401 of these three districts. In summarizing the all major components Muzaffargarh reported as most vulnerable rather than Rahim Yar
402 Khan and Rajanpur as these trends supported in literature by PDMA, (2014) and Ahmad et al., (2021).

403 **5. Conclusion and suggestions**

404 *Bait* communities of southern Punjab Pakistan are higher vulnerable due to their low lying geographical scenario in this region. In *Bait*
405 areas, agricultural land consecutively remains under affect of flood hazards and erratic rains which causes to crop losses and
406 infrastructural destructions such severe affects causes' household livelihood more vulnerable. This study focused to investigate *Bait*
407 household's vulnerability of flood hazards owing to effect of change in worldwide temperature by using the LVI. Major components
408 computed on the whole LVI illustrates as *Bait* community of Muzaffargarh (0.471) indicated more susceptible to flood disaster rather
409 than Rajanpur (0.452) and Rahim Yar Khan (0.430). The index of LVI-IPCC also explained as Muzaffargarh (0.087) *Bait* community
410 farming households were most vulnerable of flood disasters rather than Rajanpur (0.079) and Rahim Yar Khan (0.038).

411 In the scenario of study findings some significant suggestions are recommended to cope from flood disasters damages to *Bait* flood-
412 prone areas. Firstly, government needs to construct more water reserves specifically on major rivers as almost in 74 years history of
413 country two major dams Terbel (1984) and Mangla (1967) were constructed. Increasing water reserves will multiple benefits with
414 reducing floods consistency in flood prone areas, additional land available for cultivation, more access of irrigation water for
415 agriculture and increasing hydropower generation. Secondly, on State basis there is need adopt proper strategies through streamlining
416 related institutions such as local based disaster management authority, agriculture and weather department in advance get ready
417 farmers to put into practice appropriate strategically measures to avoid flood induced vulnerabilities. Proper guidance, inspiration and
418 anti disaster services need to provide farmers for adaptation of pro-active measures and improving farmers resilience from flood
419 hazards. Thirdly, State based proper policy measures for development of overhead infrastructure and more opportunities for

420 generating off farm income sources such as roads and fast communication which would facilitate flood prone Bait farmers for easy
421 access to neighbouring towns and quick escape from riverine area to safe places during flood disasters emergency. Fourthly,
422 developed communication access and social links among society through social organization participation facilitates farmers to fast
423 livelihood recoveries of health, education, sanitation and livelihood activities. Fifthly, disaster concerned authorities need to focus on
424 preparedness plan of community and early warning system that may helpful these flood-prone areas to improving and increasing
425 services access of *Bait* communities regarding extreme weather preparation with purpose to reducing ecological variations
426 vulnerabilities. Lastly while more significant as Government must specifically introduce some suitable policy measures for minimum
427 interest based loans for technical and financial assistance to flood prone Bait household farmers for facilitating in flood disasters
428 adaptation measures. In this scenario such expectations can generated as LVI components will supportive to policy marker in
429 evaluating the livelihood vulnerability to climate change impacts and develop programmes and strengthen the vulnerable sectors of
430 *Bait* communities of southern Punjab of Pakistan.

431 **Declarations**

432 Ethical Approval

433 Ethical approval taken from the COMSATS University Vehari campus, ethical approval committee

434 Consent to Participate

435 Not applicable

436 Consent to Publish

437 Not applicable

438 Authors Contributions

439 DA analyzed data, methodology, results and discussion, conclusion and suggestions and manuscript write up whereas both DA and
440 MA finalized and proof read the manuscript and both authors read and approved the final manuscript.

441 Funding

442 This study has no funding from any institution or any donor agency.

443 Competing Interests

444 The authors declare that they have no competing interest.

445

446 Availability of data and materials

447 The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

448

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634 Table 1 Livelihood vulnerability index making up through construction of sub-components and major components

Contributing factors of IPCC	Study major components	Study sub-components	Sub-components explanation with citation	Expected associations
Adaptive capacity	Livelihood strategy	Dependency on agriculture as major income source	Household percentage that having depend on agriculture as main income source (Alam, 2017)	Vulnerability increases with single dependency
		Non-farm activates of households affected by natural disasters as floods	Household percentage indicated as non-farm activities were affected by other hazards or floods (Alam, 2017)	Vulnerability increases as non-farm activates affected by floods
		Household percentage those member or head having opportunity of training to cope of other or flood disasters	Household percentage those member or head having training to cope of other hazards or flood disasters (Alam, 2017)	Vulnerability decreases with access of training
		Average agricultural livelihood diversification index [as range (0.20-1)]	Inverse of agricultural numbers livelihood activities +1 indicated by households as households that farm raises livestock and having off-farm activities will having livelihood diversification index $=1/(3+1)=0.25$ (Huong et al., 2018)	Higher the vulnerability as higher the agricultural diversification index
		Household percentage as their member working in various communities	Household percentage indicating as one of family member who participate outside community (Alam, 2017)	Vulnerability decreases as working in various communities increases
		Household percentage have job opportunities in flood season	Household percentage indicated having job opportunities in flood season	Vulnerability increases as unemployment increases
		Household percentage those fished in flood season	Household percentage having opportunities to engaging in fishing in flood season (Alam, 2017)	Household vulnerability decreases as fishing increases
	Social demographic factors	Dependency ratio	Population ratio less than 15 and more than 65 years (Shah et al., 2013)	Vulnerability increases as dependency decreases
		Household average family number members	In household family member average number (Alam, 2017)	Vulnerability increases as higher number family members
		Female headed percentage	Household percentage headed by	Vulnerability increases as female head scenario increases

			female whether male away from house almost 6 month as female headed the household activities (Hahn et al., 2009)		
		Household head percentage those not attended schooling	Household percentage those indicated as no schooling (Adu et al., 2018)	Vulnerability decreases as schooling increases	
		Literacy rate of households	In household peoples percentage those can write and read, dividing literate members in total membership households and multiply 100 (Zuroec et al., 2017)	Vulnerability increases as higher household family members	
	Social networks	Borrowing average , lending money ratio range of (0.20-1)	Household money borrowing ratio to household money lending in previous month, if household borrow money while no lend is ration 2:1, or 2 whereas if not borrow while lend money ratio 1:2 as 0.5 (Shah et al., 2013)	Vulnerability decreases as higher ratio	
		Households percentage those focus govt institutions for assistance in last twelve months	Household percentage indicated as they acquired local govt institutions for assistance in last twelve months (Hahn et al., 2009)	Vulnerability decreases as govt assistance to population increases	
		Household percentage concerned organizations of farmers	Household percentage indicated as they concerned to organizations of farmers (Alam et al., 2017)	Vulnerability decreases as increase farmers participation in farmers organizations	
		Household percentage concerned in political organization scenario	Household percentage indicated as concerned in political organization (Alam et al., 2017)	Vulnerability decreases as participation of political organization increases	
		Household percentage concerned to social organization scenario	Household percentage indicated connected with social organization (Alam et al., 2017)	Vulnerability decreases as household participation in social organization increase	
	Sensitivity	Food	Insufficient food with number of average month in range (0-12)	Households struggle to find food number of average month (Sujakhu et al., 2019)	Higher vulnerability as higher number of month
			Household percentage acquire food primarily from own farm	Household number get food from their own farm (Shah et al., 2013)	Higher vulnerability as higher number of month
Index of diversifying average crop range (0-1)			Household grown inverse number of crops +1 as those household grow	Higher vulnerability as higher index	

			cassava, pumpkin, maize diversify index = $1/(3+1)-0.25$ Alam, (2017)	
		In last three month worried about insufficient food	In last three month household percentage worried about sufficient food (Sarker et al., 2019)	Higher vulnerability higher percentage indices
		Household percentage not saving seed	Household percentage not saving their own seed from every years (Haha et al., 2009)	Higher vulnerability as higher the percentage
		Household percentage that not custom of house stead gardening	Household percentage not practices home stead gardening (Alam 2017)	Higher vulnerability as higher the percentage
	Health	Household percentage access of treatment to MBBS doctor	Household percentage generally access of treatment to MBBS doctor (Sujakhu et al., 2019)	Vulnerability decreases as qualified doctor treatment
		Health facility access in average (minute)	Household time in access health facility to nearest hospital (Hahn et al., 2009)	Vulnerability increases as time increases
		Household percentage those family members having chronic illness	Household percentage those family members having chronic illness (Sarker et al., 2019)	Vulnerability increases in chronic disease issues
		Household percentage during illness access of local doctor treatment	Household percentage during illness access of local doctor treatment (Sarker et al., 2019)	Vulnerability increase as local doctor treatment
		Household percentage sanitary latrine access	Household percentage having sanitary latrine (Sujakhu et al., 2019)	Vulnerability decreases as usage of sanitary latrine increases
		Household percentage with family members those missed their work in last two weeks due to illness	Household percentage which reported at least one family members those missed their work in last two weeks due to illness (Hahan et al., 2009)	Vulnerability increases due to illness as work missed
	Production and housing means	Households percentage without solid structure houses	Percentage of households that do not have solid structure houses (Sarker et al., 2019)	Vulnerability increases as houses without solid structure
		Household percentage affected by floods	Household percentage indicated as their houses affected due to flood (Sarker et al., 2019)	Vulnerability increases as houses affected due to flood
		Household percentage without production means	Household percentage indicated as no access to production means (Sarker et al., 2019)	Vulnerability increases as household having no production means

	Water	Household percentage indicating community based water conflicts	Household percentage that indicating having related community based water conflicts (Alam, 2017)	Higher vulnerability as higher conflicts in community
		Household percentage using unsafe or natural water source	Household percentage indicated as lake and water ponds as basic sources of water access (Hahn et al., 2009)	Higher vulnerability as drinking unsafe water
		Average time in minutes to access safe useable water from sources	Household require time to access water from primary source (Alam, 2017)	Vulnerability increases as time to access water increases
		Household percentage access easily water from tubewell	Household percentage having their own water sources (Sarker et al., 2019)	Vulnerability decreases as own water sources increases
Exposure	Climate variability	In last 10 years, gradually facing increasing summer duration	Households percentage reported increasing duration of summer in 10 years (Sarker et al., 2019)	Facing increasing vulnerability due to increasing duration in summer
		In last 10 years, gradually facing increasing winter duration	Households percentage reported increasing duration of winter in 10 years (Sarker et al., 2019)	Facing increasing vulnerability due to increasing duration in winter
		In last 10 years, gradually facing increasing winter season rainfall	Households percentage reported increasing winter season rainfall in 10 years (Sarker et al., 2019)	Facing increasing vulnerability due to increasing winter season rainfall
		In last 10 years, gradually facing increasing monsoon rainfall	Households percentage reported increasing monsoon rainfall in 10 years (Sarker et al., 2019)	Facing increasing vulnerability due to increasing monsoon rainfall
		In last 10 years, gradually facing increasing rainfall	Households percentage reported increasing rainfall in last 10 years (Sarker et al., 2019)	Facing increasing vulnerability due to increasing heavy rainfall
		In last 10 years, gradually facing increasing occurrence of hailstorm	Households percentage reported increasing occurrence of hailstorm in last 10 years (new)	Facing increasing vulnerability due to increasing occurrence of hailstorm
		In last 10 years, gradually facing increasing occurrence of riverbank erosion	Households percentage reported increasing occurrence of riverbank erosion in last 10 years (Alam, 2017)	Facing increasing vulnerability due to increasing occurrence of riverbank erosion
		In last 10 years, gradually facing increasing temperature	Households percentage reported increasing temperature in last 10 years (Alam, 2017)	Facing increasing vulnerability due to increasing temperature
		In last 10 years, gradually	Households percentage reported	Facing increasing vulnerability due to increasing floodwater

		facing increasing floodwater	increasing floodwater in last 10 years (Alam, 2017)	
	Natural disasters	In last 10 years, flood events average number	Households reported total number of floods (Alam,2017)	Higher flood numbers increased vulnerability
		In last 10 years, drought events average number	Households reported total drought numbers (Alam, 2017)	Higher vulnerability due to higher drought
		In last 10 years, household respondents percentage death and injured due to flood hazards	In last 10 years households reported death or injuries due to flood hazards (riverbank erosion, hailstorms, floods, thunderstorms) (Alam, 2017)	Households as higher as higher percentage of injuries
		In last 10 years average numbers embankment was breached	In last 10 years households reported number of riverbank embankment was breached	Higher vulnerability as higher number embankment was breached
		Household percentage that not received warning of natural disasters (embankment breach, hailstorms, flash floods)	Household reported the percentage not received warning before hazards (Alam, 2017)	Households higher the vulnerable the number of times not receiving warning prior to hazards
		The month average number waterlogged land	Households reported number of month land as water logged	Higher the vulnerability as higher number of month

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649 Table 2 Three districts each sub-component livelihood vulnerability indices minimum, maximum and actual values

LVI major components	LVI sub-components	Measurement unit	Muzaffargarh district	Rahim Yar Khan district	Rajanpur district	All districts maximum value	All districts minimum value
Adaptive capacity							
Livelihood strategy	Dependency on agriculture as major income source	%	94	78	93	100	0
	Non-farm activities of households affected by natural disasters as floods	%	77	69	75	100	0
	Household percentage those member or head having opportunity of training to cope of other or flood disasters	%	8	13	9	100	0
	Agricultural livelihood average diversification index as range (0.20-1)	1/livelihood	0.37	0.37	0.37	1	0.20
	Household percentage as their member working in various communities	%	32	28	31	100	0
	Household percentage have job opportunities in flood season	%	27	43	28	100	0
	Household percentage those fishing in flood season	%	39	37	38	100	0
Social demographic factors	Dependency ratio	Ratio	0.59	0.34	0.58	3	0
	Household average family number members	Count	7.8	6.3	7.2	26	0
	Female headed percentage	%	9	5	7	100	0
	Household head percentage those not attended schooling	%	89	78	86	100	0
	Literacy rate of households	%	29.6	34.1	30.04	100	0
Social networks	Borrowing average , lending money ratio range of (0.5-2)	Ratio	1.43	1.51	1.45	2	0.50
	Households percentage those focus govt institutions for assistance in last twelve months	%	67	59	63	100	0
	Household percentage concerned organizations of farmers	%	27	36	28	100	0
	Household percentage concerned in political organization scenario	%	34	47	35	100	0
	Household percentage concerned to social organization scenario	%	13	25	14	100	0
Sensitivity							
Food	Insufficient food with number of average month in range (0-12)	Months	3.4	2.3	3.1	12	0
	Household percentage acquire food primarily from own farm	%	91	83	89	100	0

	Index of diversifying average crop range (0-1)	1/crops	0.48	0.48	0.48	1	0
	In last three month worried about insufficient food	%	89	78	83	100	0
	Household percentage not saving seed	%	28	19	27	100	0
	Household percentage that not custom of house stead gardening	%	25	16	21	100	0
Health	Household percentage access of treatment to MBBS doctor	%	57	49	44	100	0
	Health facility access in average (minute)	Minutes	178.91	154.01	169.87	450	0
	Household percentage those family members having chronic illness	%	21	12	19	100	0
	Household percentage during illness access of local doctor treatment	%	96	81	93	100	0
	Household percentage sanitary latrine access	%	43	31	39	100	0
	Household percentage with family members those missed their work in last two weeks due to illness	%	19	12	16	100	0
Production and housing means	Households percentage without solid structure houses	%	92	76	89	100	0
	Household percentage affected by floods	%	95	87	94	100	0
	Household percentage without production means	%	41	32	38	100	0
Water	Household percentage indicating community based water conflicts	%	27	19	24	100	0
	Household percentage using unsafe or natural water source	%	31	23	28	100	0
	Average time in minutes to access safe useable water from sources	Minutes	5.7	3.8	4.9	18	0
	Household percentage access easily water from tubewell	%	68	66	67	100	0
Exposure							
Climate variability	In last 10 years, gradually facing increasing summer duration	%	89	84	86	100	0
	In last 10 years, gradually facing increasing winter duration	%	5	6	7	100	0
	In last 10 years, gradually facing increasing winter season rainfall	%	43	38	37	100	0
	In last 10 years, gradually facing increasing monsoon rainfall	%	71	68	69	100	0
	In last 10 years, gradually facing increasing rainfall	%	83	76	77	100	0
	In last 10 years, gradually facing increasing occurrence of hailstorm	%	47	43	40	100	0
	In last 10 years, gradually facing increasing	%	68	65	66	100	0

	occurrence of riverbank erosion						
	In last 10 years, gradually facing increasing temperature	%	88	81	83	100	0
	In last 10 years, gradually facing increasing floodwater	%	78	75	77	100	0
Natural disasters	In last 10 years, flood events average number	Count	4.9	4.7	4.6	6	0
	In last 10 years, drought events average number	Count	1.2	1	1.1	2	0
	In last 10 years, household respondents percentage death and injured due to flood hazards	%	13	8	11	100	0
	In last 10 years average numbers embankment was breached	Count	3.2	2.1	2.7	5	0
	Household percentage that not received warning of natural disasters (embankment breach, hailstorms, flash floods)	%	37	19	29	100	0
	The month average number waterlogged land	Months	5.4	4.1	4.9	12	0

662 Table 3 Normalized sub-components and major components Livelihood Vulnerability indices (LVI)

Major components	Muzaffargarh district	Rahim Yar Khan district	Rajanpur district	Sub-components	Muzaffargarh district	Rahim Yar Khan district	Rajanpur district
Adaptive capacity							
Livelihood strategy	0.403	0.419	0.427	Dependency on agriculture as major income source	0.940	0.780	0.930
				Non-farm activities of households affected by natural disasters as floods	0.770	0.690	0.750
				Household percentage those member or head having opportunity of training to cope of other or flood disasters	0.080	0.130	0.090
				Agricultural livelihood average diversification index as range (0.20-1)	0.254	0.254	0.252
				Household percentage as their member working in various communities	0.320	0.280	0.310
				Household percentage have job opportunities in flood season	0.270	0.430	0.280
				Household percentage those fishing in flood season	0.190	0.370	0.380
Social demographic factors	0.158	0.176	0.174	Dependency ratio	0.196	0.113	0.193
				Household average family number members	0.198	0.154	0.167
				Female headed percentage	0.090	0.050	0.070
				Household head percentage those not attended schooling	0.110	0.220	0.140
				Literacy rate of households	0.196	0.341	0.300
Social networks	0.424	0.491	0.429	Borrowing average , lending money ratio range of (0.5-2)	0.712	0.789	0.745
				Households percentage those focus govt institutions for assistance in last twelve months	0.670	0.590	0.630
				Household percentage concerned organizations of farmers	0.270	0.360	0.280
				Household percentage concerned in political organization scenario	0.340	0.470	0.350
				Household percentage concerned to social organization scenario	0.130	0.250	0.140
Sensitivity							
Food	0.515	0.438	0.490	Insufficient food with number of average month in range (0-12)	0.283	0.191	0.258
				Household percentage acquire food primarily from own farm	0.910	0.830	0.890
				Index of diversifying average crop range (0-1)	0.480	0.480	0.480
				In last three month worried about insufficient food	0.890	0.780	0.830
				Household percentage not saving seed	0.280	0.190	0.270

				Household percentage that not custom of house stead gardening	0.250	0.160	0.210
Health	0.460	0.365	0.414	Household percentage access of treatment to MBBS doctor	0.570	0.490	0.440
				Health facility access in average (minute)	0.398	0.342	0.377
				Household percentage those family members having chronic illness	0.210	0.120	0.190
				Household percentage during illness access of local doctor treatment	0.960	0.810	0.930
				Household percentage sanitary latrine access	0.430	0.310	0.390
				Household percentage with family members those missed their work in last two weeks due to illness	0.190	0.120	0.160
Production and housing means	0.760	0.650	0.737	Households percentage without solid structure houses	0.920	0.760	0.890
				Household percentage affected by floods	0.950	0.870	0.940
				Household percentage without production means	0.410	0.320	0.380
Water	0.360	0.303	0.337	Household percentage indicating community based water conflicts	0.270	0.190	0.240
				Household percentage using unsafe or natural water source	0.310	0.230	0.280
				Average time in minutes to access safe useable water from sources	0.181	0.134	0.157
				Household percentage access easily water from tubewell	0.680	0.660	0.670
Exposure							
Climate variability	0.635	0.595	0.602	In last 10 years, gradually facing increasing summer duration	0.890	0.840	0.860
				In last 10 years, gradually facing increasing winter duration	0.050	0.060	0.070
				In last 10 years, gradually facing increasing winter season rainfall	0.430	0.380	0.370
				In last 10 years, gradually facing increasing monsoon rainfall	0.710	0.680	0.690
				In last 10 years, gradually facing increasing rainfall	0.830	0.760	0.770
				In last 10 years, gradually facing increasing occurrence of hailstorm	0.470	0.430	0.400
				In last 10 years, gradually facing increasing occurrence of riverbank erosion	0.680	0.650	0.660
				In last 10 years, gradually facing increasing temperature	0.880	0.810	0.830
				In last 10 years, gradually facing increasing floodwater	0.780	0.750	0.770
Natural disasters	0.501	0.386	0.444	In last 10 years, flood events average number	0.816	0.783	0.766
				In last 10 years, drought events average number	0.600	0.500	0.550
				In last 10 years, household respondents percentage death and injured due to flood hazards	0.130	0.080	0.110

				In last 10 years average numbers embankment was breached	0.640	0.420	0.540
				Household percentage that not received warning of natural disasters (embankment breach, hailstorms, flash floods)	0.370	0.190	0.290
				The month average number waterlogged land	0.450	0.341	0.408
Overall livelihood vulnerability index (LVI)					0.471	0.430	0.452

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690 Table 4 Livelihood vulnerability index with contributing IPCC factors

Contributing factors of IPCC	Values of contributing factors IPCC			Major components	Values of major components		
	Muzaffargarh district	Rahim Yar Khan district	Rajanpur district		Muzaffargarh district	Rahim Yar Khan district	Rajanpur district
Adaptive capacity	0.328	0.362	0.343	Livelihood strategy	0.403	0.419	0.427
				Social demographic factors	0.158	0.176	0.174
				Social networks	0.424	0.491	0.429
Sensitivity	0.524	0.439	0.495	Food	0.515	0.438	0.490
				Health	0.460	0.365	0.414
				Production and housing means	0.760	0.650	0.737
				Water	0.360	0.303	0.337
Exposure	0.568	0.491	0.523	Climate variability	0.635	0.595	0.602
				Natural disasters	0.501	0.386	0.444
Livelihood vulnerability index of IPCC (LVI-IPCC)					0.087	0.038	0.079

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703 Figure 1 Map of study area three districts Punjab province Pakistan

718 Figure 2 Map of three study districts Muzaffargarh, Rahim Yar Khan and Rajanpur showing surrounding rivers
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729 Figure 3 Three Bait households districts Livelihood Vulnerability Index (LVI) major components with spider diagram

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Figure 4 Three districts Bait community vulnerability LVI-IPCC scores in triangle diagram