Flood hazards vulnerability and risk of food security in Bait community flood-prone areas of Punjab Pakistan: In SDGs achievement threat

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Abstract
Climate change in the global perspective has increased the occurrence of natural disasters, which subsequently decreased agricultural production and intensified the issue of food security. Developing countries, such as Pakistan, are facing severe food security issues, where most of the population still experiences poverty and hunger in their daily lives. Flood disasters ruin valuable land, cause agricultural production losses, and interrupt livelihood routines as expected household livelihood becomes more vulnerable. This research work focused on investigating the flood hazards vulnerability and risk of food security in the Bait community flood-prone areas of Punjab, Pakistan, with a broader aspect in contrast to previous research work. A constructed food security index composed of several IPCC and FAO factors with correlated dimensions of food security was used for the empirical estimation in this study. A composite food security index was developed through polychoric principal component analysis. To estimate the influence on the overall food security condition in the study area, a food security index was regressed on various independent variables. Estimates of the study indicated that three-fourths of household respondents in the study area are confronted with the issue of food security with changeable scale. Financing schemes, physical assets, and family type illustrated the positive influence on respondents’ food security level, whereas respondents suffering property losses owing to floods had a negative influence. The study findings suggested integrated strategies must be adopted to effectively deal with issues of food security in the scenario of increasing severity of flood disasters. Policymakers and disaster-concerned institutions need to develop disaster risk mitigation strategies by constructing new water reserves and clearing river encroachments to deal with flood disasters. Agricultural research and development authorities need to provide climate friendly seed varieties and promote particular food crops for flood prone areas to ensure food security and reduce livelihood vulnerability, specifically for the flood-prone communities.

Keywords Climate change · Flood hazards · Riverbank erosion · Food security · Punjab · Pakistan

Introduction
In the global scenario, within the past couple of decades, the intensity and frequency of natural hazards, specifically floods, landslides, drought, cyclones, and earthquakes, have risen (Teo et al. 2018; Ahmad and Afzal 2020a, b; Week and Wizor 2020; Elahi et al. 2021), due to increasing temperature and related climatic variability (Tirivangasi 2018; Eckstein et al. 2019; Hoq et al. 2021; Ahmad and Afzal 2021a, b; Ahmad and Afzal 2022). Floods are considered the most destructive and consecutive (Daniell et al. 2016; Ahmad et al. 2019; Houng et al. 2019) due to substantial human fatalities, economic losses, and social risks (Kreft et al. 2016; IPCC 2017; Ahmad and Afzal 2021a, b, c, d, e, f). In 2017 globally, almost 96 million people were severely affected by natural hazards (Emergency Event Database 2017; World Bank 2021), in which more
than 60% were affected by flood disasters (Huq et al. 2019; IPCC 2020). During the past couple of decades, increasing severity and recurrence of floods have been estimated, specifically in South East Asian and South Asian countries (Hirabayashi et al. 2013; Eckstein et al. 2019), where a few countries from the Asian region such as Bangladesh, China, Pakistan, and India were declared the supermarkets of flood disasters (James and James 2010; Mahmood et al. 2016; Teo et al. 2018). In the future, increasing intensity and severity of flood hazards are expected in the Asian region (Ahmad et al. 2019; IPCC 2020) which consequently affects regional disparities regarding onset and distribution, causes higher losses to accumulate in nations of the Asian region (Abbas et al. 2017; UNSCCC 2021; Sam et al. 2021; Ahmad et al. 2022a, b).

Pakistan was ranked the world’s 5th most affected country regarding climate change natural disasters because of frequent floods and being situated in a hazard-prone region (Eckstein et al. 2019; IPCC 2020). Erratic rain, an expanding monsoon rainfall cycle, and glacier melting are some considerable factors linked to successive floods in interlinked rivers regarding downstream and upstream (Abid et al. 2015; Teo et al. 2019; Ahmad and Afzal 2020a, b). In natural hazards and particularly in relation to flood disasters, from 1950 to 2014, Pakistan repeatedly faced 22 serious flood hazards (Yaqub et al. 2015; Ali and Erenstein 2017; Shah et al. 2017). The flood disaster of 2010 was the worst one, and it adversely affected 24 million people, destroyed 2 million cropped areas, and the cumulative estimated cost was $10 billion (United Nations 2011; Abbas et al. 2017; Ahmad et al. 2021a, b). During a flood in 2011, the highest rainfall ever recorded severely affected 2.7 million people in southern Balochistan and Sindh, caused 434 human fatalities, damaged 1.52 million homes, and destroyed 6.79 million acres of crops (PDMA Punjab 2017). Heavy monsoon rains significantly affected 4.85 million people of Sindh, Punjab, and Balochistan in 2012, causing the destruction of 1.172 million cropped acres and 571 human fatalities (PDMA Punjab 2018). In 2013, heavy monsoon rains caused flash floods and affected 1.5 million people, destroyed a cropped area of 1.6 million acres and caused 234 human fatalities (BOS 2016). In 2014, flash flooding in major rivers affected Gilgit-Baltistan, Kashmir, and Punjab causing 350 human fatalities, vast destruction of homes, and cropped areas (PDMA Punjab 2019).

In developing countries, the increasing intensity and frequency of flood events have many implications for the livelihood of the population (Abbas et al. 2018; Sam et al. 2019; Ahmad et al. 2019), specifically by distressing availability and access of food, thus obstructing attaining SDGs of the UN, particularly the SDG-2 focused on endorsing sustainable agriculture, improving nutrition, attaining food security, and hunger eradication by 2030 (Banik 2019). Food security is regarded as a worldwide human right (WHO 2018) and achieving food security is a vital objective that can be attained through maintaining affordable health and a sustainable supply of food (Perez-Escamilla 2017; Ahmad and Afzal 2021a, b, c, d, e, f). In the global scenario, least-developed and developing countries are constantly confronted with the major challenge of achieving food security and almost 820 million people do not have sufficient food for their hunger satisfaction (WHO 2018). In Pakistan, the green revolution was introduced in 1960 with advanced inputs of high yield seed varieties, fertilizer, pesticides, tubewell, mechanization through tractor, and other advanced technologies (Khan and Makki 1980; Chaudhry 1982; Khan 1983), which caused a hyper increase in agricultural outputs, reduced income inequalities in rural areas consequently contributing to reduced poverty and food insecurity issues even though the population of the country doubled (Choudhry 1994; Khan and Gul 2013). Furthermore, multiple measures such as mostly five-year plans, public policies of hunger eradication, and rapid economic growth helped to fight the food insecurity issue in the country (United Nations 2018; GOP 2019; Ahmad and Afzal 2020a, b; Sun et al. 2021). Despite all such feasible measures, in Pakistan currently, 12.9% of the population are undernourished (FAO 2019), where 1.3% of employed people earn less than $1.90 per day (ADB 2021) and in the official scenario, 21.5% of the population lives below the poverty line, with rural 27.6% and urban 10.7% of the population (Ahmad and Afzal 2019; Haroon et al. 2021). Currently, the extreme climate scenario and its variations have increased the issue of food security of previously vulnerable peoples. Furthermore, climatic variations have increased the tendency of floods frequency, which hinders the measures to reduce the issues of food security in Pakistan and poses an alarming threat to attaining food security.

Food security is closely linked with climate change where outcomes of the food system (Arouri et al. 2015; Frelat et al. 2016; Choithani 2020) and climate-based natural disasters could push 122 million people, particularly farmers, into extreme poverty by 2030 (FAO 2019; Thiede and Gray 2020). In Pakistan, almost 63% of the rural population

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1. Intergovernmental Panel of Climate Change.
2. United Nations Security Council and Climate Change.
3. Provincial Disaster Management Authority.
4. Bureau of Statistics.
depend on natural resources for their livelihood (PBS\textsuperscript{9} 2020) and recurrent flood hazards seriously threaten agricultural production and increase uncertainty of farmer livelihood (Ahmad and Afzal 2021a, b, c, d, e, f). Humans need food for their survival; the repercussion of flood disasters is terrible because of insufficient accessibility, constrained utilization, and reduced access to food (Abbas et al. 2018; Pingali et al. 2019). Household food security managing capabilities are reduced due to long-term exposure of floods and farmers consequently have to switch their assets to handle flood risks (Hwalla et al. 2016; Kantor et al. 2017; Chien et al. 2021; Ahmad and Afzal 2022). In the global scenario, rural communities are particularly confronted with the manifested effects of floods such as reduced agricultural production, diminished employment, lower purchasing power, increased health issues, higher and severe threats of poverty, malnutrition, food insecurity, and enhanced hunger.

In the general scenario of flood vulnerability of households, food security is considered a robust indicator. Deluges have severe implications regarding food security, as they hinder access, availability, utilization, and stability of food (Vervoort et al. 2014; Abbas et al. 2018; Ahmad et al. 2020). Food security is the function of access, availability, utilization, and stability of food as SDG-2 broadly covers the outcomes of these four dimensions (FAO 2019; ADB 2021).

Floods impact on food security and the significance of the four dimensions fluctuates over time, across regions, and most importantly related to the whole socioeconomic conditions of the country. Punjab province is formally known as the land of the fertile area of five rivers Ravi, Sutlej, Jehlum, Indus, and Chenab (BOS Punjab 2020). In Pakistan, Indus and Chenab are major rivers of the country (PBS 2020) that frequently flood and cause destruction in the summer season due to extreme erratic rains and extreme snow melting because of intense climate change variations (PM\textsuperscript{10} 2019; Ahmad and Afzal 2021a, b, c, d, e, f). In natural flowing progression, such rivers are scattered in various impermanent inland waterways while crossing in the course of various areas as impermanent islands are frequently engendered in the river areas. In the southern Punjab region, such impermanent islands in the rivers are identified as Bait\textsuperscript{11} areas in the local language Saraiki. Farming communities specifically populated adjacent to these river areas mostly inhabit and carry out their farming on such islands and cultivate these areas of Bait. All such areas of Bait are under direct threat from rivers in flooding seasons. During rainy seasons and floods, such Bait communities face the destruction of crops, infrastructure, human fatalities, livestock losses, and damage to shelters. The parallel flows of the Indus and Chenab rivers have increased the flood hazards vulnerability of the Southern Punjab region (PDMA Punjab 2019). The frequent scenario of floods has severely affected Bait farmers’ livelihoods and harshly increased food security issues in contrast to the farmers in other regions because of inadequate flood hazard mitigation measures, including insufficient allocation of resources and measures for hazards mitigation, lack of awareness and communication, and partial function of hazards institutions in Bait areas of southern Punjab.

In literature regarding global and Pakistan perspectives, the food security aspect has been discussed in various dimensions, where some significant studies have focused on the factors affecting food security (Abu and Soom 2016; Olaiyiwola et al. 2017; Russell et al. 2018; Zhou et al. 2019; Ahmad et al. 2019; Lokruka 2020; Mekonnen et al. 2021; Rose and Adil 2021; Khng et al. 2022), household level aspects of food expenditures, food consumption, and nutritional security (Li and Yu 2010; Carletto et al. 2013; Alexandri et al. 2015; Hasanah et al. 2017; Carpena 2019; Harris et al. 2020; Ahmad and Afzal 2021a, b, c, d, e, f; Valluri et al. 2021; Sarkar et al. 2022), and nutritional security and informative level as availability of food (Leroy et al. 2015; Sseguya et al. 2018; Green et al. 2020; Kogo et al. 2021). Furthermore, in the scenario of flood-prone communities, the household-level food security aspect was elaborated in a few studies (Di Falco and Bulte 2011; Ajaero 2017; Balana et al. 2020; Alhassan 2020), flood hazards and human displacement (Tong 2017; Ober 2019; Balana 2020; Alhassan 2020), flood hazards and livelihood vulnerability (Kabenge et al. 2017; Weldegebriel and Amphune 2017; Rudiarto and Pamungkas 2020; Ahmad and Afzal 2021a, b, c, d, e, f; Chien et al. 2021; Few et al. 2021; Kam et al. 2021; Zhongming et al. 2021), and flood hazards and livelihood vulnerability (Kabenge et al. 2017; Weldegebriel and Amphune 2017; Rudiarto and Pamungkas 2020; Ahmad and Afzal 2021a, b, c, d, e, f; Hoq et al. 2021; Yang et al. 2021; Ahmad et al. 2022a, b).

In the above-cited literature, flood hazards are discussed with some significant aspects, including the aspect of flood hazards with food security in the global scenario. However, no significant study exists on flood hazards and food security with the particular aspect of SDGs objectives and FAO dimensions focused on flood-prone areas of Pakistan according to the best knowledge of the authors. Hence, it is a prerequisite to the application of an unrestrained approach for estimating household level food security to include the four dimensions of food security: food access, availability, utilization, and stability. To better understand food security, it is necessary to do extensive research of relevant links among factors such as land access, production, ownership of assets, health, malnutrition and availability of water. In addition, food security in regard to recurrent floods and climate change has foremost significance for adaptation by farmers and policy decisions.

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\textsuperscript{9} Pakistan Bureau of Statistics.

\textsuperscript{10} Pakistan Metrological Department.

\textsuperscript{11} Temporary islands are usually generated within the area of the river in the local language Saraiki is formally known as Bait.
Owing to inadequate information about flood risks, mitigation programs and adaptation policies cannot be effectively formulated. In such background, food security investigation involves the dimensions of access, availability, utilization, and stability as central elements significantly affecting the food security of households in flood hazards areas. Furthermore, such an approach is comprehensive in nature because it combines food security FAO dimensions and climate change IPCC dimensions and is thus positioned to provide appropriate policy-related and empirical insights. In this scenario according to the research gap mentioned above and using a comprehensive approach, this study focused on these specific objectives first by considering the four dimensions to examine the status of food security in flood-prone Bait communities of Punjab, Pakistan. Second, by establishing the association in vulnerability indicators of climate change and food security in flood-prone Bait communities of Punjab, Pakistan. This study is divided into five sections: the introduction was the first section, the second section elaborates the conceptual framework, and the material and method are discussed in the third section. The results and discussion are given in section four, and the last section highlights conclusions and suggestions.

**Study based conceptual framework**

In the previous research scenario, some studies discussed the changeable levels of dimensions in most frameworks of food security, and a significant food security framework was developed particularly focusing on linking pathways of agriculture to food security outcomes (Kanter et al. 2015; Garrett et al. 2017; Sassi 2018). The mechanism linked the outcomes of agriculture and food security more appropriately and directly suggested by a pathway in these frameworks (Renzaho and Mellor 2010). Most food security frameworks addressed the perspective of developed countries in the context of political, cultural, and social aspects of these outcomes. The significance of this framework in contrast to other frameworks is that it confined the modulation variation of food security regarding various cultures, for example, in conventional communities food security severity is estimated in terms of hunger among adults in contrast to children. In particular, these frameworks are based on the food security aspect of FAO while not properly related to the IPCC concept to climate change vulnerability. This study used the food security FAO approach linked with various climate change dimensions of IPCC. Food security (family base) at the household level for the description of cultural variations was used to capture the food shortage. In nature, this approach is comprehensive and hence presents an improved policy linked and empirical approach.

This research work suggests an advanced framework in flood and food security research through associating the food security dimensions (FAO) with climate change dimensions (IPCC), as illustrated in Fig. 1. Household-level is a strong indicator regarding the overall vulnerability to flood, food security implies the capability to overcome any unanticipated occurrence, including sickness, unemployment, and decreased earnings (Shah and Dulal 2015). As a dimension of food security, food availability is concerned with the suitable and adequate quantity of food available to households throughout the year by import or domestic resources (Swaminathan and Bhavani 2013). Food access indicates the scenario in which all community members have sufficient earnings to attain the appropriate quality of food substance composing a healthy diet for a healthy lifestyle. The food access dimension has unified functions of different institutional, social, physical, and policy-based environments that settle on effective utilization and access of resources for making certain food security goals among households. The dimension of food utilization comprises access to ample diet, health care, clean water, and sanitation to attain a state of dietary wellbeing, and it is more particularly related to the implication of non-food inputs in the food security scenario. Food stability is a household’s ability to obtain adequate food when losing access to earning means permanently or temporarily. Losing access to earning means jointly or solely could spearhead income shocks and result in inadequate resources for sufficient consumption (Shah and Dulal 2015). Food stability includes the capability to secure the food security dimensions of food access, availability, and utilization in due course (Hwalla et al. 2016).

The scenario of vulnerability is particularly and relatively based on a system or person. Systems vulnerability delineates the state of affairs that differentiates a group or person to weigh their capability to predict how well they could cope with fatal events, mitigate and recover from the impact of such disaster after its onset (Adger 1999; Blaikie and Maldavrin 2014). Vulnerability is formally known as the function of exposure, susceptibility, and adaptive capacity. Adaptive capacity refers to the system as the proportion of resources to utilize preference and approaches of risk management to get ready for, restrain or evade and recover from the effects of exposure to natural disasters. Exposure indicates the presence of people’s livelihoods, environmental services, infrastructure and capital resources (social, economic, cultural) in areas that could be fully and partially ramshackle (Aleksandrova et al. 2014). Susceptibility is illustrated as the tendency of a person or system to be negatively impacted by experiencing or change in climate disasters (Birkman et al. 2013). Household-level adoption of vulnerability functions causes food security declines in the dimension of sensitivity as it is extremely susceptible to the least type of natural hazards. More particularly the adaptive capacity of the household is constituted by physical, economical, and social
characteristics. Climate change and floods constitute exposure dimensions that affect households.

**Material and methods**

**Selection of study area**

Khyber Pakhtunkhwa, Sindh, Punjab, and Balochistan are four provinces of Pakistan, and because of some considerable factors, Punjab is more preferable for this study. First, Punjab is favored because it has a major share (53%) in agricultural GDP, is the most populated (52.95%), and covers 26% area of the country (BOS Punjab 2019; PBS 2021). Second, this province in contrast to other provinces faces higher severity of flood disasters owing to the successive flowing of the five major rivers of the country throughout the fertile lands of Punjab (PDMA Punjab 2019). Third, in the province, the region of southern Punjab is particularly focused for study because it has faced consecutive flood disasters due to its location at the eastern and western bank of the largest river, the Indus river (NDMA 2019; GOP 2020). Fourth, in the southern Punjab region, Bait communities were particularly focused because these communities mostly inhabited temporary islands owing to Indus river distributive riverine channels and mostly engaged in farming activities, and consecutive flood disasters increased their farming vulnerability. Last, among seven higher flood risk Bait community districts, three were chosen for the study – Dera Ghazi Khan, Rajanpur, and Muzaffargarh – according to their severity of flood risk, as indicated in Fig. 2.

**Geographical features of the study area**

Dera Ghazi Khan covers an area of 11,294 km², has a population of 2.87 million, is administratively categorized in four tehsils, Taunsa, Kot Chhutta, Dera Ghazi Khan, and DE-Excluded Area Dera Ghazi Khan, and consists of 98 union councils (GOP 2017; BOS Punjab 2019). Dera Ghazi Khan is classified as a low socio-economic status district based on the provincial social progress index because of low social, cultural, and economic dimensions (BOS Punjab 2018). Frequent variations in the climatic scenario of the district occur, with extremely hot summers and mild winters, with a maximum 51 °C and minimum -1 °C temperature, and an average rainfall of 104 mm (PMD 2019). The critical location of the district is the reason for extreme hazards as the eastern side is located on the bank of the Indus river, which causes riverine flood, and on the western side, the Koh-Suleman mountain range causes flash floods during the erratic rainy season (NDMA 2018; PDMA Punjab 2019). For a couple of decades, this district faced erratic rain and frequent floods that caused human fatalities, losses of livestock, destruction of crops and infrastructure (BOS Punjab 2020).
Administratively, the Muzaffargarh district consists of four tehsils, Kot Addu, Jatoi, Muzaffargarh and Alipur, with 4.3 million people, an area of 8249 km², and 93 union councils (GOP 2017; PBS 2021). Muzaffargarh is regarded as a highly vulnerable district to frequent flood disasters and is situated in a critical geographical location surrounded by two major rivers; on the eastern side of the Chenab river flows and the western side of the Indus river flows (PDMA Punjab 2018; BOS Punjab 2019). This area has 127 mm average rainfall, lowest 1 °C and highest 54 °C temperature, with a relatively hot summer season and mild winter season (PMD 2020). In the past two decades, Muzaffargarh faced consecutive floods and erratic rainfall, which caused major losses of livestock, crops, human fatalities, and destruction of infrastructure (PDMA Punjab 2018). This district is also categorized as low socioeconomic in the province because of lower social, economic, and cultural dimensions according to the lower social progress index (BOS Punjab 2020).

Rajanpur district is administratively categorized into three tehsils Rojhan, Rajanpur, and Jampur, 69 union councils with an area of 12,318 km² and a population of 1.99 million (GOP 2017; PBS 2020). The Rajanpur district has with mild winters, a long and hot summer season, with lowest 1 °C and highest 52 °C temperature, and an average rainfall of 119 mm (PMD 2019). Rajanpur is highly vulnerable due to flood hazards from the critical geographical scenario of being located on the western bank of the Indus river (GOP 2019). Erratic rains and riverbank erosion of the Indus river caused consecutive flooding in rural areas of the district resulting in extreme destruction of infrastructure, human fatalities, losses of livestock and crops (PDMA Punjab 2018). Because of lower social, economic, and cultural dimensions and a lower social progress index, this district is categorized as a low socioeconomic area in the province (GOP 2019).

### Sampling method and data collection

In this study, a multistage sampling method was employed for the collection of data first, and due to the higher destruction and vulnerability of floods, Punjab was among four provinces chosen for the study (NDMA 2018). Second, the region of southern Punjab and particularly the Bait communities were specifically preferred in this study due to frequent floods and higher vulnerability (BOS Punjab 2019). Third, three riverine Bait community districts (Dera Ghazi Khan, Rajanpur, Muzaffargarh) among seven Bait community districts were chosen for the study owing to their higher severity of flood hazards (PDMA Punjab 2019), as indicated in Fig. 3. Fourth, based on higher flood vulnerability, two tehsils from every district and two union councils from tehsils were chosen according to information provided by the agriculture officer, land record local officer (patwari), and DDMA. Last, according to vulnerability and destruction
of flood hazards, two villages of Bait communities from each union council were chosen and 16 respondents were randomly selected and were interviewed from each village. For data collection, major respondents were household heads (male/female) and households illustrated as the basic unit in the study area. The sampling method of Cochran (1977), as shown in Eq. (1), was specifically applied to obtain the minimum data in this study. Heads of households were particularly focused on for data collection of 384 household respondents, where 5% of the population was adequate for the study sample (Kottrlik and Higgins 2001). SS illustrated the sample size in Eq. 1, where \( Z(\pm 1.96 \text{ at } 95\%) \) indicated confidence interval for point picking, \( p \) choices percentage, (0.5 used required size of sample) explained decimal, and \( e(0.07 = \pm 7) \) is the precision value.

\[
SS = \frac{Z^2(p)(1 - p)}{e^2}
\]  

(1)

Respondents in the study area were directly connected, a well-developed and pre-tested questionnaire was applied for data collection from September to November 2019. For accuracy and adequacy of information, a questionnaire to avoid vagueness was applied for the pilot study and through 24 respondents pre-tested before starting the appropriate survey. The author himself and six trained enumerators clarified and corrected all related matters about questionnaires before beginning the data collection procedure in the study area. Respondents in the study area were properly informed concerning the use and purpose of data collection, respondents who refused to contribute their information were substituted with other respondents.

**Food security index (FSI)**

Regarding different individuals, communities, regions, and nations, the various status of food security was estimated (Arouri et al. 2015). Food security is preferably measured...
by a few methods such as HFIAS\textsuperscript{15} and FAO for estimation of household expenditure and income survey, per capita calories available at the national stage, and individual basis dietary intake measurement. Furthermore, no single approach is able to address all dimensions of food security in the given period, in the same scenario no organization or institute has the mandate or capability to monitor or assess food security taking into consideration all of its different dimensions (Carletto et al. 2013).

Household level food security was measured by adopting the developed food security index (Sam et al. 2021), and a systematic method was used in its construction, which is the combination of composite indices (Antony and Rao 2007; Mutabazi et al. 2015). The food security index is based on a weighted index, which elaborated a single composite indicator with the combination of various four dimensions and 11 key indicators in this food security index, as indicated in Table 1. Household family farm dependency for food consumption, the sufficiency of food, and the food expenditure of households are significant indicators of household food availability. Individual household holding livestock, PDS\textsuperscript{16} access, and farmland area are included in dimensions of food access. Crop diversification, food supplies instability, and reduction in yield are illustrated as dimensions of food stability. Household-level potable water accessibility issues and malnutrition problems highlight the dimensions of food utilization.

The principal component analysis (PCA) method was used to estimate the food security indicators procedure of acquiring weighting objectives. Some discrete indicators were also estimated in the food security index such as whether some households have water access issues. Discrete variables usage caused a violation of the PCA assumption of Gaussian distribution and consequently led to biased

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|}
\hline
Food security FAO dimensions & Food security indicators & Indicators explanation & Sources of indicators \\
\hline
Availability of food & Household expenditure on food & Per month household average food expenditure in PKRs & Paul (2014) \\
Sufficient food all year long & Household having sufficient food for consumption all over dummy variable = 1 otherwise = 0 & Pangaribowo et al. (2013) \\
Family farm dependency for food & Household having family farm dependency for food production dummy = 1 otherwise = 0 & Food and Agriculture Organization (2013) \\
Access of food & Cultivated land area & Cultivated total land area in acres & Frelat et al. (2016) \\
Access of public distribution system & Household depending on public distribution system for items of subsidized food dummy variable = 1 otherwise = 0 & Food and Agriculture Organization (2006) \\
Holding livestock & Available total number of livestock in the household & Valdivia (2001) \\
Stability of food & Loss of crop yield & Household facing loss of crop and yield due to flood dummy variable = 1 otherwise = 0 & Savary et al. (2012) \\
Food supply instability & Household facing food supply instability from shop or market due to idiosyncratic or covariate shocks dummy variable = 1 otherwise = 0 & Devereux (2007) \\
Index of crop diversification & Inverse of number of edible crops cultivated by households + 1 & Wani et al. (2012) \\
Utilization of food & Problems of water access & Household facing issue regarding in access of irrigated or potable water dummy variable = 1 otherwise = 0 & Sinyolo et al. (2014) \\
Issues of malnutrition & Household facing issue of malnutrition dummy variable = 1 otherwise = 0 & Pangaribowo et al. (2013) \\
\hline
\end{tabular}
\caption{Food security index variables}
\end{table}

\textsuperscript{15} Household Food Insecurity Access Scale.  
\textsuperscript{16} Public Distribution System.
findings. In such a scenario, polychoric PCA was used to overcome the issue of assumption violation. The calculation of the food security index is performed in equation form in 2 and 3, afterward the estimation of polychoric PCA.

\[ PC_{mn} = \sum_{i} f_{n}^{i}(X_{m}^{i}) \]  

In Eq. (2) \( n \) is the nth household respondents and \( m \) indicates mth components regarding the \( PC_{mn} \). In the same way \( f_{n}^{i} \) the nth component is factor loading for nth indicator, and the \( X_{m}^{i} \), highlights the factors of mth households respondents.

\[ FSS_{m} = \sum_{n} V_{n}(PC_{mn}) \]  

Equation (3) has elaborated the \( FSS_{m} \) as composite mth household respondents food security score and nth principal components variance as \( V_{n} \). Food security score (FSS) is employed in Eq. (4) for developing the Food Security Index (FSI), which ranges from scale 0 to 1.

\[ FSI_{n} = \frac{FSS_{m} - FSS_{min}}{FSS_{max} - FSS_{min}} \]  

| Major factors          | Sub-factors                                | Types of variables | Explanation of factors                                                                 | Sign of factors |
|------------------------|--------------------------------------------|--------------------|---------------------------------------------------------------------------------------|-----------------|
| Demographic factors    | Type of family                             | Dummy variable     | Household living in joint family = 1 other wise = 0                                   | (+)             |
|                        | Household head                             | Dummy variable     | Female is household head = 1 other wise = 0                                          | (-)             |
|                        | Age of household head                      | Continuous variable| Household head age in years                                                           | (+)             |
|                        | Mother literate                            | Dummy variable     | Female or mother related to cooking literate = 1 other wise = 0                      | (+)             |
|                        | Social caste                               | Dummy variable     | Members of family belong to backward cast socially = 1 other wise = 0                | (-)             |
| Social factors         | Access to school                           | Dummy variable     | Household having access to school = 1 other wise = 0                                 | (+)             |
|                        | Informal money lenders access              | Dummy variable     | Household having access to money lenders = 1 other wise = 0                          | (-)             |
|                        | Money borrowing from kin                   | Dummy variable     | During crisis money borrowed from kin = 1 other wise = 0                             | (+)             |
| Economic factors       | Benazir Income Support programme (BISP) Pakistan | Dummy variable     | Members of household joined BISP = 1 other wise = 0                                 | (+)             |
|                        | Household migration                        | Dummy variable     | Household having at least one member migrated = 1 other wise = 0                     | (+)             |
|                        | Access to bank                             | Dummy variable     | Household having access to bank = 1 other wise = 0                                  | (+)             |
| Physical factors       | Structure of housing                       | Dummy variable     | Household having permanent house = 1 other wise = 0                                 | (+)             |
|                        | Household durable assets                   | Continuous variable| Household having total number of durable assets                                       | (+)             |
| Floods factors         | Property losses                            | Dummy variable     | Households faced losses of property (durable assets, house, livestock) during the flood period of 2010 to 2015 = 1 other wise = 0 | (-)             |
|                        | Facing stress                              | Dummy variable     | Household facing stress due to flood = 1 other wise = 0                             | (-)             |
|                        | Rainfall average variation                 | Dummy variable     | Household reported any variation in average rainfall during 2010 to 2015 = 1 other wise = 0 | (-)             |
|                        | Environmental deterioration affects on income earning | Dummy variable | Household income affected due to environmental deterioration from climate change and floods = 1 other wise = 0 | (-)             |
In Eq. (4) mth household respondent’s food security index is indicated as \( FSI_m \), and the sample maximum food security score value is denoted as \( FSS_{\text{maximum}} \) and \( FSS_{\text{minimum}} \) illustrated the minimum food security score of the sample of the study area.

### Beta regression empirical model

Food security score as the dependent variable of the model consists of the factors that determine the food security of Bait flood-prone rural households, which is the function of economic, social, demographic, flood, and physical factors. These major factors are part of a combination of 18 sub-factors. Sub-factors denoted as independent variables of the model indicated the expected sign of coefficient estimated, as illustrated in Table 2. Equation (5) elaborated the model of the study, as indicated below.

\[
FSS_m = \alpha + \beta_l X_m + u_m
\]  

(5)

In Eq. (5), mth household’s composite food security score is indicated as \( FSS_m \), and sub-factors variables under exposure and adaptive capacity dimensions explained as \( X_m \) and respective coefficients are denoted as \( \beta_l \). The food security index considers a continuous variable with an interval \((0, 1)\) in this model and correlated to added variables in the structure of regression. Hence, the beta regression model employed in this study is a replacement for normal regression because this model is based on the distribution of beta density in terms of parameters and mean (Ferrari and Cribari-Neto 2004). In this study, maximum likelihood (ML) was employed to estimate the parameters of the model and in the STATA benefit package used for model implementation. Average marginal effects were estimated by employing margin commands. Direct interpretation of the average marginal effect can be estimated, unlike the estimated coefficient. In the scenario of continuous variable, the average marginal effect would be incidental as an added unit of increase in the variable increases the score of food security by coefficient level. In the status of the dummy variable more caution is needed for interoperation where percentage changes are inferred regarding the coefficient form of 0 and 1.

### Results and discussion

The food security index replicates the selection of food security dimensions, which proceeds through the preliminary stage of performing polychoric PCA regarding the dataset of 11 indicators. Eigenvalue criterion considers the base for factors selection, and those factors having Eigenvalues greater than one were selected for the study. Four components C1, C2, C3, and C4 were selected based on this criterion, which indicated the total variance of 78.89%. Component one (C1) and two (C2) have the Eigenvalues 3.971 and 1.83 and have variance of 34.68% and 17.49%, and component three (C3) and four (C4) have Eigenvalues 1.36 and 1.09 and showed variance of 12.53% and 10.12%. In Table 3, estimates of polychoric PCA are illustrated in which the framework of PCA indicated the correlation in component and indicators is known factor loading and discloses the details shared by components and indicators (Mutabazi et al. 2015). Each indicator variance proportion was illustrated through the component is indicated via loading square (Abdi and Williams 2010) in which each indicator’s highest loading factor was applied for food security score construction as elaborated in Eq. 2.

### Table 3 Polychoric principal component analysis

| Dimension of food security | Food security indicators | Components* |
|----------------------------|--------------------------|-------------|
|                            |                          | Component 1 | Component 2 | Component 3 | Component 4 |
| **Availability of food**   | Household expenditure on food | –0.054 | 0.781 | –0.124 | 0.187 |
|                           | Sufficient food all over the year | 0.003 | 0.793 | 0.156 | –0.171 |
|                           | Family farm dependency for food | 0.879 | 0.068 | –0.113 | 0.002 |
| **Access of food**         | Cultivated land area | 0.698 | 0.049 | 0.241 | 0.337 |
|                           | Access of public distribution system | –0.287 | 0.151 | 0.598 | 0.003 |
|                           | Holding livestock | 0.299 | 0.327 | –0.286 | –0.184 |
| **Stability of food**      | Loss of crop yield | 0.894 | –0.039 | –0.143 | –0.047 |
|                           | Food supply instability | –0.011 | –0.048 | 0.006 | 0.899 |
|                           | Index of crop diversification | –0.893 | 0.016 | 0.114 | 0.187 |
| **Utilization of food**    | Problems of water access | 0.887 | 0.021 | –0.127 | 0.004 |
|                           | Issues of malnutrition | 0.069 | –0.138 | 0.784 | 0.017 |

* showing the uppermost component loading
Area of agricultural land, loss of crop yield, diversification of crops, issues of water access, and family farm food dependency indicators have the uppermost loading related to component 1. In component 2, the maximum loading factor was estimated regarding the indicators number of livestock, sufficient food for all over the year, and household monthly food expenditure. In the scenario of component 3, the highest loading factor was for the issue of malnutrition and public distribution system, whereas the highest factor loading was related to the indicator of food supply instability in component 4. In component analysis, all food security indicators were significantly related to indicators of food security, and these findings are similar with the studies of Glago (2019), Kakinuma et al. (2020), and Ahmad and Afzal (2021a, b, c, d, e, f).

The impact of social, demographic, physical, economic, and flood factors on rural household food security was investigated using beta regression model coefficients and calculated variables average marginal effect, as depicted in Table 4. The marginal effect demonstrates where each independent variable alteration confirmed changes in outcomes, and estimates the predictable alteration in the probability of a preference being completed concerning a unit variation in independent variable due to mean (Green 2000). Family type and demographic profile are the most prominent demographic sub-factors that significantly and positively affect the food security of rural households. Particularly in rural areas of Pakistan, a joint family system is the common practice where family members work together, live together, and share family expenses; therefore, such a joint family system regarding various household issues is used as a shock-absorbing approach, and these results of the study are in contrast to the study of Green et al. (2020) and in line with the studies of Kamo (2000), Leroy et al. (2015), Sseguya et al. (2018), Kogo et al. (2021), and Ahmad et al. (2021a, b). Family elderly members are considered the decision-making body of the household where each household has more than one earning family member that all significantly contribute to the household’s overall economic scenario. Households often

### Table 4 Different sub-factors impact on household food security

| Food security major factors | Food security sub-factors | Coefficients of beta regression | Marginal effect |
|-----------------------------|---------------------------|---------------------------------|-----------------|
| Demographic factors         | Type of family            | 0.389**(0.091)                  | 0.087**(0.019)  |
|                             | Household head            | -0.274**(0.112)                 | -0.058**(0.021) |
|                             | Age of household head     | 0.008**(0.003)                  | 0.003**(0.001)  |
|                             | Mother literate           | 0.176(0.158)                   | 0.043(0.039)    |
|                             | Social caste              | 0.024(0.071)                   | 0.006(0.018)    |
| Social factors              | Access to school          | 0.159**(0.073)                  | 0.041**(0.017)  |
|                             | Informal money lenders access | 0.029(0.081)                  | 0.009(0.023)    |
|                             | Money borrowing from kin  | -0.089(0.077)                  | -0.019(0.016)   |
| Economic factors            | Benazir Income Support programme (BISP) Pakistan | 0.274**(0.091) | 0.498**(0.017)   |
|                             | Household migration       | 0.499**(0.104)                  | 0.123**(0.022)  |
|                             | Access to bank            | -0.127(0.121)                  | -0.031(0.029)   |
| Physical factors            | Structure of housing      | 0.113(0.091)                   | -0.034(0.031)   |
|                             | Household durable assets  | 0.249**(0.038)                  | 0.054**(0.006)  |
| Floods factors              | Property losses           | -0.187**(0.079)                 | -0.049**(0.021) |
|                             | Facing stress             | -0.017(0.081)                  | -0.004(0.019)   |
|                             | Rainfall average variation | 0.091(0.083)                   | 0.026(0.021)    |
|                             | Environmental deterioration affects on income earning | 0.083(0.077) | 0.023(0.021)   |
|                             | Constant                  | -1.983**(0.287)                 | 2.734**(0.097)  |
|                             | Ln-phi                    |                                |                 |

Parenthesis shows the standard error values, ***show 1% level of significance **shows 5% level of significance.
prefer to increase food expenses regarding the enhancement of economic status. Landholding and assets ownership are kept joint in the joint family system causing fragmentation avoiding in landholding of the family. Landholding fragmentation may lead to complete termination of agriculture or reduce agricultural products output that will eventually generate issues of food security for rural area households, and these results of the study are inconsistent with the studies of Zhou et al. (2019), Ahmad and Afzal (2020a, b), Lokuruka (2020), and Mekonnen et al. (2021).

Household head status considerably influences rural households’ food security. Estimates of the study illustrated the significant and negative influence of the household head in rural areas’ food security. In the study area, the majority of household heads (79%) are male and limited numbers (21%) of household heads are females, where females become household heads because of male head migration, disruption, family conflicts, and male death (Kassie et al. 2014). Female-headed households faced higher issues of food security than male-headed households because of children responsibilities, maintenance of the household, mobility restrictions, ownership of limited land, labor markets wage disparities, and levels of lower literacy, and these findings are in contrast with the studies of Hasanah et al. (2017) and Harris et al. (2020) and consistent with the studies of Alexandri et al. (2015), Carpena (2019), Ahmad and Afzal 2021a, b, c, d, e, f; Valluri et al. (2021), and Sarkar et al. (2022). Household food security is notably influenced by the age of the household head because more significant decisions related to family are made by the household head. It is presumed that older household heads have acquired more knowledge through longer experience of farming practices, substantial environment and social interactions. Aged household heads are considered higher risk-averse and with increasing age more likely to be food secure, and these findings are in line with the studies of Muche et al. (2014), Weldegebriel and Amphune (2017), Rudiarto and Pamungkas (2020), Ahmad et al. (2021a, b), and Yang et al. (2021).

In a crisis scenario, institutional networks, social connections, and communal integration are considerable factors in achieving food security at a household level. Estimates indicated the school access variable reflects a positive and significant effect as household-level in-school access considerably improves household-level food security. Household-level overall food security is not directly connected to school, but it facilitates helping children attending schools to develop food security, and these findings are in line with the studies of Hasanah et al. (2017), Carpena (2019), Harris et al. (2020), Ahmad and Afzal (2020a, b), Valluri et al. (2021), and Sarkar et al. (2022). In 2011, the Punjab government introduced the policy for Free Lunch for primary schooling which was instigated to develop nutrition for school-going children (GOP 2011). This scheme makes available at no cost cooked lunches to school children, which consequently facilitated poor children to regularly attend school and become healthy. This helps those children related to the disadvantaged segment of society with insufficient access to food possibly have adequate intake.

In Pakistan, the Benazir Income Support Programme (BISP) was launched in July 2008 (GOP 2009) and results of the study indicated a positive and significant correlation between BISP and food security reflecting that BISP financial assistance makes food security more feasible, particularly for rural households (PBS 2019). BISP was launched with the particular objective of poverty reduction with unconditional cash transfer which will ultimately increase the purchasing power of the underserved population (GOP 2020) and leads to improve household level food security. In this study, a positive and significant association was estimated regarding migration and food security of households. The majority of households depend on agriculture for their livelihood, which is a very risky source for earnings because this area is highly prone to flood hazards. Households through performing small business practices, migrating to nearby states or cities, and participating in daily labor activities are diversifying their incomes. In most developing countries, migration has become a significant aspect of strategies of livelihood because remittances are a welcome source of income for migrant-sending households (Choi 2017). The major share of poor household income is spent on food, and the remittances by migrants have a direct positive effect on households’ income, and these findings are in line with the studies of Naylor and Falcon (2010), Zezza et al. (2011), Sseguya et al. (2018), Green et al. (2020), and Ahmad and Afzal (2022). The income status of a household is considered one of the significant sources for influencing hunger and food security, where increasing income status directly reduces hunger because some basic food items (preferred food, oil, salt) are neither bartered nor domestically produced and require cash to purchase (Silvestri et al. 2015; FAO 2019).

In the food security scenario, there is a considerable role of household assets, which significantly improve the ability of households to withstand unanticipated changes. The managing capability of households related to issues of food security depends on their various access to assets (Ellis and Manda 2012). Selling durable assets is a major and common practice among poor rural populations in severe climatic hazards areas (McKernan et al. 2018; Ahmad and Afzal 2022). Households mostly purchase durable assets in sound financial times (wealthy periods) and sell these durable assets to purchase life necessities during a financial crisis (negative income shocks). In such a scenario, these durable assets are an instrument for safeguarding the food security of...
households during extreme climatic conditions; therefore, it can be presumed that households with more physical assets are more food secure. The findings of the study reflected the significant and positive effect of rural households’ food security and durable assets. Household assets are considered their resource stocks, which can easily indirectly or directly converted for survival means (Silvestri et al. 2015; McKeran et al. 2018). Increasing various durable assets is the element of food security that enhances household’s capacity regarding the issue of seasonal food security and sudden economic shocks as such durable assets are highly liquid for cash conversion, and hence findings of the study are in line with the studies of Renzaho and Mellor (2010), Russell et al. (2018), Zhou et al. (2019), Lokuruka (2020) Ahmad et al. (2020) and Mekonnen et al. (2021).

In the scenario of rural population food security, floods have some considerable indirect and direct effects. Livestock losses, destruction of standing food crops, and damage to shelters and grain storage are some direct effects of floods on food security, whereas indirect effects of floods on food security are domestic violence, social unrest, compromised health, and reduced purchasing power (Skoufias 2003; Brouwer et al. 2007; Ahmad et al. 2020). In study areas, recurrent floods almost every year for a couple of decades caused severe losses of lives, livestock, crops, and property. The above subsections reported indirect losses related to flood vulnerability and floods in the scenario of food security in the region of the study areas but also reflected the direct effect of floods on the food security status of respondents. In Table 4, findings of the study showed property losses owing to flood event onsets considerably destabilized the household status of food security. Property losses because of floods distressed the food security situation as an indirect effect; on the other hand, property losses integrated with losses of crops, livestock, and grain stored with durable assets had a direct and strong bearing on the regional food security. The marginal effect of such variable was significant and complemented the role of property loss on regional food security conditions. More particularly, an increase of 1% probability of property loss owing to floods was indicated to reduce food security status by 5%. Furthermore, stress owing to floods had an anticipated earlier sign, illustrating the negative association with household status of food security; however, the correlation was non-significant statistically. Related variables such as deterioration in environment income-earning and average rainfall variation owing to the incidence of the flood were illustrated to have a non-significant or diminutive impact on the food security status of the household. These results show floods effect food security by disturbing or destroying household inventories and assets basis, and the findings are in contrast with the studies of Zhou et al. (2019) and Lokuruka (2020) and similar with the studies of Alexandri et al. (2015), Hasanah et al. (2017), Carpena (2019), Harris et al. (2020), Valluri et al. (2021), Ahmad et al. (2022a, b), and Sarkar (2022). In the scenario of property loss, a significant variable indicated floods rising impact on household-level consumption of food, food availability and comprised based nutrition uptake. In the major factors group of the flood, other variables are not as significant in affecting the food security of people because of the lower or equal to 5% marginal effect. In such consideration, the rising vulnerability of flood leads to rising losses of property, which significantly affects food security levels in the population. These findings have multiple implications such as conditionally protecting assets of households which will include mitigation in severe scenarios of disaster on multiple bases, and these findings are consistent with the studies of Bulte et al. (2011), Ajaero (2017), Balana et al. (2020), Alhassan (2020), Ahmad et al. (2021a, b), and Ahmad and Afzal (2022). Adopting the insurance mechanism, particularly in flood-prone areas to safeguard the durable assets of households is considered one of the significant measures in severe climatic dynamics surrounding regions such as Pakistan.

**Conclusion and suggestions**

Human livelihood routine matters such as economic performance, health care, water access, agricultural production, and human livelihood have been severely affected by flood disasters, which has raised household food security issues. Nutritional security, patterns of food consumption, and food expenditures aspects are the focus of many studies, whereas limited research work has directly contributed related to factors of nutritional security and food consumption. This study used the composite index approach to investigate food security with a focus on components that influence the pattern of food consumption, food expenditure, and nutritional security. The Southern Punjab region of Punjab province, Pakistan is more preferably focused for the study due to being subsistence agricultural dependent, a less developed area in the region, and a high-risk flood-prone area in the province. This region has higher severity of flood disasters due to frequent floods, lower socioeconomic status in the region, and facing higher dimensions of hunger and poverty. Estimates of the study indicated mostly rural flood-affected households are facing issues of food security. Such conditions need the implementation of intervention policies to reduce future risks of rising levels of food insecurity owing to intensified frequent floods. This study also examined the factors that affect household food security and calculated each significant variable average marginal effect. The study findings indicated physical assets, education, BISP, and structure of joint family positively and significantly affect food security.
In the study area, the provision of social support and alternative employment opportunities are more feasible measures for reducing the food security issue. Generating additional employment opportunities by developing agro-based industries through public–private cooperation is practicable financing policy measures in local flood-prone areas which will ultimately boost food security. Non-agricultural employment opportunities need to be promoted in local areas because such sources are a feasible way to earn and maintain livelihood when agricultural income fails due to hazards. Food security is indirectly or directly affected due to household vulnerability to flood hazards. Assurance plans of food security and non-agricultural income are substantial; therefore, it is essential to concentrate on base-level indicators that direct to food security. In contrast to previous studies, this study used the broader aspect of food security by including all dimensions of FAO and incorporating climate change dimensions of IPCC regarding flood hazards in flood-prone areas. In the broader perspective of Pakistan, local, regional, and national-based disasters managing authorities such as NDMA, PDMA, and DDMA need to develop feasible short-term and long-term plans of disaster mitigation, particularly in disaster-prone areas. In overcoming the intensity of flood disasters the concerned authorities need to implement feasible measures such as constructing new water reserves, increasing the capacity of existing reserves, paving the riverbanks to overcome riverbank erosion, clearing river encroachments, and developing disasters awareness and mitigation understanding among flood-prone inhabitants. Application of such strategies preserves valuable land, ensures food security, reduces the destruction of crops, infrastructure and homes, and inhabitants’ livelihood will be more secured. This study has the major limitation of focusing on a limited area and respondents due to financial constraints as such conclusions can address only a limited perspective. In the future, the study perspective needs to extend to the provincial and national level, which will be more feasible for drawing national and regional level policy strategies.

Author contributions DA analyzed data, methodology, results and discussion, conclusion and suggestions, and manuscript write-up. Both DA and MA finalized and proofread the manuscript. Both authors read and approved the final manuscript.

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Declarations

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

Consent to Participate Not applicable.

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