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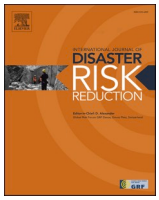

Flood vulnerability and food security in eastern India: A threat to the achievement of the Sustainable Development Goals

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ABSTRACT

The food security situation in India has improved due to economic growth, increased agricultural productivity, public policies and hunger eradication programmes. Nevertheless, much of India's population still suffers from hunger and poverty. Floods obstruct agricultural production; destroy infrastructure; and disrupt livelihoods, normal services, health care, etc. In this way, floods ultimately affect households' food security. We examined household food security in flood-prone rural areas of India in a more extensive way than in previous studies by constructing an index that incorporates various factors of the food security dimensions. Factors determining the level of flood-prone households' food security were also analyzed. By polychoric principal component analysis, an aggregate food security index was constructed. The food security score was regressed on different explanatory variables to evaluate their effect on the overall food security situation in the study area. Our results showed that three-fourths of the respondent households faced food security issues to varying degrees. Family type, physical assets and employment scheme showed positive impacts on the level of food security of the respondents. In contrast, households with female household heads and those suffering losses of property due to floods were adversely affected in terms of negative impacts on overall food security. The results suggest the need for the adoption of integrated strategies to effectively address food security issues amidst the increased severity of flood events. The study findings are useful for policy makers in India and countries with similar backgrounds to tackle the food insecurity brought about by flood hazards.

1. Introduction

Rising temperatures and other climatic variabilities are likely to increase the frequency and intensity of natural hazards, especially floods, in many South Asian countries [1,2]. As noted by Ref. [3]; future flood impacts are likely to influence regional disparities in terms of distribution and onset, with the highest losses accruing in nations within the Asian continent. Among the countries of South Asia, India is worst affected by various natural disasters, and it has the highest number of flood-related deaths [4]. According to the Government of India, a total area of 49.82 million hectares (15% of the total area of the country) is flood prone in the country [5]. From 1900 to 2020, India faced 304 floods that affected 30 million people and took more than 1500 lives every year [6,7]. The country has also witnessed an increase in flood events during the last decade (2010–2020). For instance, in 2013, the state of Uttarakhand in India experienced catastrophic heavy rainfall ultimately culminating in disastrous floods, which caused the death of over 6000 individuals along with an economic loss of more than USD 3.8 billion [8,9]. Another major flood event occurred in Chennai city in Tamil Nadu state during 2015, which took many lives and caused an economic loss of USD 2.2 billion [10]. The flood of 2018 in Kerala state was the worst in approximately a century, causing economic damage of

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3.7 billion USD and a death toll of more than 450 people [8]. Furthermore, in 2020, various states in India, e.g., Odisha, Bihar, Telangana, Maharashtra, Assam, were also hit by severe floods. It is estimated that 0.8% of India's GDP is vulnerable to flood hazards, which could increase more than tenfold by the end of 2030 [11].

Increases in the frequency and intensity of flood events have many repercussions for people's livelihoods in a variety of ways [12,13]. The main impacts of increased floods in developing countries could lead to severe implications for human survival by disturbing access to and availability of food, thus presenting obstacles to achieving the Sustainable Development Goals (SDGs) of the United Nations, especially SDG-2 aimed at eradicating hunger, achieving food security, improving nutrition and promoting sustainable agriculture by the end of 2030 [14]. Food security is considered a universal human right [15]. Attaining food security is paramount and can be achieved by maintaining an affordable, sustainable and healthy food supply [16]. However, attaining food security continues to be one of the greatest challenges faced by developing countries and the least-developed countries globally. According to the Food and Agriculture Organization (FAO) of the United Nations (2019), worldwide, nearly 820 million individuals do not have enough food to satisfy their hunger.

In India, the green revolution spearheaded a historic move towards the achievement of food security in the 1960s through the introduction of high-yielding varieties of cereals [17]. This led to the tripling of food grain production over the next four decades and consequently contributed to reducing food insecurity and poverty in the country by over 50% despite the increasing population during the period, which almost doubled. In addition, with the initiation of five-year plans by the government of India, the country experienced a substantial rise in cropped area, input application, increased irrigation facilities and growth of mechanization. Moreover, these five year plans also helped increase food grain production almost six fold, from 50.8 million tonnes to 291 million tonnes between the 1950–51 and 2019–20 crop years [18,19]. Over these years, many hunger eradication public policies and programmes have also helped fight food insecurity issues within the country. Although since 1990, the country has witnessed rapid economic growth [20], it is home to more than 300 million poor people and 194.6 million undernourished individuals. It is pertinent to note that almost 30% of the country's rural population lives below the poverty line. Climate change and climate extremes have enhanced the food security issues of these already vulnerable people. In addition, floods and changing climates hinder various efforts to reduce food security issues in India and cause significant threats to food security. Therefore, achieving food security is a matter of prime importance for India.

Food security is an outcome of a food system and is essentially linked with the changing climate, which is one of the environmental drivers interacting with the food system [21]. The [22] reported that climate change and natural disasters could push another 122 million people, mainly farmers, into extreme poverty by 2030. Frequent floods in India have increased the vulnerability of rural people who depend on natural resources for their livelihood. In India, the agricultural sector provides livelihood opportunities to more than 60% of the rural population [23]. Floods seriously threaten agricultural production and increase the uncertainty of small-scale farmers' livelihoods. As food is one of the basic needs of humans, the aftermath of flood events is dire due to less availability, reduced access and constrained utilization of food [24]. Long-term exposure to floods reduces households' ability to manage food security problems, as they are forced to divest their assets to cope with flood risks [25]. The overall impact of floods is manifested in the form of a reduction in agricultural production, weakening of purchasing power, decreased employment opportunities and an increased number of health issues, leading to serious threats of poverty, hunger, food insecurity, and malnutrition, especially among rural communities internationally [26].

Food security is a robust indicator of overall household vulnerability to floods. Floods and their resultant inundations have serious implications for food security, as they threaten food availability (production, storage, processing), access, stability and utilization [27]. The Food and Agriculture Organization (FAO) of the United Nations defines food security as a function of food availability, access to food, stability and utilization of food [15]. SDG-2 is comprehensive and is focused on outcomes, covering in large part all four dimensions of food security [28]. The importance of these dimensions and the overall impact of floods on food security differs across regions and over time and, most importantly, depends on the overall socioeconomic status of a country.

The issues related to households' food security are often investigated with a myopic viewpoint and narrow framework. The core concepts discussed in many studies are food consumption, nutrition security and food expenditure patterns of households [29–31]. Studies on food consumption and nutrition security are vital, but they only provide information about the 'food availability' dimension of food security while putting less emphasis on the other dimensions, which are also critical for overall households' food security condition [32–35]. In addition, various studies have been conducted to quantify the overall food security conditions of households that are prone to natural disasters [36–39]. None of these studies covered all the dimensions of food security described by the FAO, and less emphasis was placed on linking and analyzing different dimensions of food security and climate change vulnerability. Therefore, a more expansive approach is needed to estimate the food security of households by incorporating all four dimensions (availability, access to food, stability and utilization) of food security. To widen the concept of food security, the vital linkages among production, access to land, asset ownership, malnutrition, health, water availability and a set of other relevant structural factors must be studied extensively. Furthermore, food security in a changing climate and frequent floods are of prime importance for policy decisions and farmers' adaptation in the country. Due to the lack of such information, improved adaptation policies and programs to mitigate flood risk cannot be formulated in an effective way.

In such a milieu, investigating food security, ipso facto, in terms of the dimensions of 'availability, access, stability and utilization' has become paramount to facilitate understanding of the core elements critically influencing households' food security in flood-prone areas. In addition, our approach is holistic in nature, as it combines the Intergovernmental Panel on Climate Change (IPCC) dimensions of climate change with the FAO's dimensions of food security and is thus positioned to provide better empirical and policy-related insights. Within this context, the particular objectives of this work include (1) to investigate the food security status of flood-prone rural households in India by considering four dimensions of food security and (2) to determine the relationship between food security and climate change vulnerability indicators among flood-prone households in rural India.

2. Conceptual framework

In the literature, different food security frameworks with varying levels of emphasis and dimensions are available. [40,41]; and [42] developed a framework focused on food security and specified pathways linking agriculture to food security outcomes. The illustrative pathways in these frameworks more directly suggest the mechanisms by which agricultural system outcomes and food security outcomes are linked [43]. food security framework is focused on the developed country perspective and considers the social, cultural, and political contexts in which these outcomes occur. One key difference in this framework compared to other frameworks was that it captured the nuanced differences in food security of different cultures; for instance, in traditional communities the severity of food security is measured in terms of hunger among adults rather than among children. Although these frameworks are fundamentally based on the FAO concept of food security, they are not connected with the climate change vulnerability concept of the IPCC. In our study, we adopt the FAO's approach of measuring food security in the context of climate change by linking the IPCC dimensions

of climate change. To capture food shortages, we use household-level food security (any family members) to account for cultural differences. This approach is holistic in nature and thus positioned to provide better empirical and policy-related insights.

This study proposes a new framework in food security and flood research by linking the dimensions of food security (adopted from the FAO) with the dimensions of climate change (adopted from the IPCC) (see Fig. 1). As a strong indicator of the overall vulnerability of households to floods, food security alludes to the ability to absorb any unforeseen event, including loss of earnings, unemployment or sickness [44]. Among the various food security dimensions, food availability is the availability of food in sufficient quantity with appropriate quality, made available through either domestic production or/and imports [45]. Food access is the situation when all individuals have enough means to obtain an appropriate quantity of food items constituting a nutritious diet for a healthy being. In addition, this dimension (food access) is an integrated function of various environments (the physical, social, institutional and policy environments) that determine effective access and utilization of resources for ensuring food security objectives among households [15]. The food utilization dimension is related to the availability of clean water, ample diet, sanitation and healthcare for realizing a state of nutritional well-being. This dimension is more linked with the significance of nonfood inputs in the case of food security. Food stability concerns households that face a high risk of losing access to the ways and means, temporarily or permanently, needed to ensure the consumption of enough food. Losing access to such means is solely or jointly spearheaded by income shocks, lack of enough reserves for adequate consumption, or both [44]. Food stability involves the ability to secure the other three dimensions of food security, viz., availability, access and utilization, over time [46].

Vulnerability is either person or system specific. The vulnerability of a system is defined as the situation characterizing a person or group that influences/constrains their capacity to anticipate a deadly event, mitigate, cope with and recover from the impact(s) of such a disaster after its onset [47,48]. It is a function of adaptive capacity, susceptibility and exposure [49]. [50] explained the adaptive capacity of a system as the extent of resource use choices and risk management approaches to prepare for, avoid or moderate, and recover from the effects of an exposure to natural hazards. Susceptibility is defined as the tendency of a system/person to be negatively impacted by changes in climate or experiencing a natural hazard [51]. Exposure is defined as the presence of people, infrastructure, livelihoods, environmental services and resources, or capital (cultural, economic or social) in places that could be partly or fully dilapidated [52]. When vulnerability functions are adopted at the household level, food security falls in the sensitivity dimension, as it is highly susceptible to any kind of natural disaster. The demographic, social, economic, and physical characteristics of a household constitute its adaptive capacity. The exposure dimension consists of flood and climatic variability that affects households.

3. Study area

The state of Odisha in India was selected for this study. This state lies on the eastern coast, and the geographical coordinates of the state are between the $17^0 49'$ and $22^0 36'$ northern latitudes and between the $81^0 36'$ and $87^0 18'$ eastern longitudes. The following reasons justify our selection of this study area. (1) Odisha is recognized as the disaster capital of the country due to multiple disasters, such as cyclones, floods, droughts and earthquakes [53]. The average annual rainfall within the state is 1451.2 mm. The state receives maximum rainfall from the southwest monsoon from the months of June until September. Floods inundate the affected areas for approximately one to two weeks in many parts of coastal belts, causing damage to life and household assets, which affects the food security of the victims. (2) Odisha is primarily an agriculture-dominated state. Agriculture and allied subsectors contribute approximately 19.91% to the gross state domestic product as per advance estimates for 2019–2020 while providing livelihood opportunities to approximately 49% of the total labor force, either directly or indirectly [54,55]. The gross cropped area in Odisha during 2018–2019 was 8.3 million hectares [56]. However, the productivity and efficiency of resource use remain generally low within the state due to the low yields and high instability brought about by climatic variations and climatic extremes at various physiological growth stages of crops [57]. (3) Odisha is considered as the least-developed state in India. Moreover, consumption expenditures, health, education, household facilities, female literacy, poverty rate, financial inclusion, urbanization rate, etc., are also at low levels [58]. The rural population is approximately 35 million (83.3% of the total population) in the state, while approximately 32.6% of the state's population lives in poverty [56,59].

4. Sampling and household survey

A total of 220 households were sampled from a total of 1363 households in the four villages (Beguniabasta, Gopalpur, Alanda and Manijanga) from the Puri District of Odisha using simple random sampling. A survey questionnaire was developed to gather information on food security and flood aspects of the households. The survey also gathered data regarding the social, demographic, economic and physical characteristics of households.

5. Research methodology

5.1. Food security index (FSI)

A vast difference can be found in the food security status of various communities, nations, regions and individuals [60]. To measure household food security status, quite a few methods are used by scholars, viz., the FAO approach for the estimation of calories available per capita at the national scale, surveys on household income and

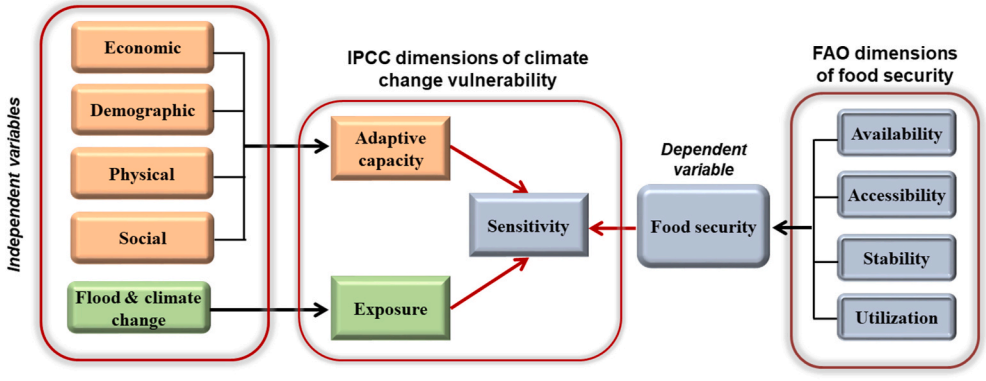

Fig. 1. FAO's food security dimensions viz-à-viz the IPCC's climate vulnerability dimensions – a theoretical framework.

expenditure, measurement of dietary intake on an individual basis, anthropometry, the Household Food Insecurity Access Scale (HFIAS), etc. However, none of these methods is solely able to utilize all required indicators for the desired time period(s), while at the same time, no single institution/organization has the ability or mandate to evaluate and monitor food security considering all of its dimensions on various levels [30].

We constructed a FSI to measure the food security of households. To construct this FSI, a systematic approach was used in this work to construct composite indices [61,62]. The FSI was constructed as a weighted index that combines different indicators of food security dimensions into a single composite indicator. A set of 11 key indicators that represent the four dimensions of food security were used for the construction of the FSI. The indicators and their explanations are elucidated in Table 1. The indicators of food availability are household food expenditure, food sufficiency and dependency of households on family farms for food consumption. Agricultural land area, access to PDS and number of livestock of an individual household are incorporated in the food access dimension. To represent the food stability dimension, the indicators used are yield reduction, instability of food supplies and crop diversification. The food utilization dimension consists of issues of malnutrition and problems of accessing potable water for household activities.

Table 1
Indicators employed in the construction of the FSI.

FAO dimensions of food security	Indicators	Explanations	Sources
Food availability	Household food expenditure	The average food expenditure per month of households in US$	[63]
	Adequate food throughout the year	A dummy variable = 1 if household has sufficient food for consumption year-round, otherwise = 0	[64]
	Dependence on family farm for food	A dummy variable = 1 if household depends on family farm products for food, otherwise = 0	[65]
Food access	Cultivated land area	Total cultivated land area in acres[b]	[66]
	Public Distribution System (PDS)[a] access	A dummy variable = 1 if household depends on the PDS for subsidized food items, otherwise = 0	[67]
	Livestock	Total number of livestock available in the household	[68]
Food stability	Crop/yield loss	A dummy variable = 1 if household faced any yield loss due to flood, otherwise = 0	[69]
	Instability of food supply	A dummy variable = 1 if household faced any instability of food supplies from markets or shops due to any covariate and idiosyncratic shocks, otherwise = 0	[70]
	Crop diversification index	The inverse of the number of edible crops cultivated by the household +1	[71]
Food utilization	Water access problems	A dummy variable = 1 if household faced any issues regarding the access to potable or/and irrigation water, otherwise = 0	[72]
	Malnutrition issues	A dummy variable = 1 if household faced any malnutrition issue, otherwise = 0	[64]

[a] The PDS is an initiative by the Government of India. It is a network of fair-price shops assigned with the work of distributing basic food commodities to the disadvantaged sections of society to guarantee food security.

[b] One acre of land equals 0.405 ha.

A Principal Component Analysis (PCA) was performed to attain an objective-weighting procedure for estimating the indicators of food security. Few indicators used to calculate the FSI were discrete, for example, the indicator of whether households have problems with water access. When we used these discrete variables, the Gaussian distributional assumption of PCA was violated, which ultimately led to biased findings. Hence, to avoid this violation, we adopted polychoric PCA. Once the polychoric PCA was carried out, Food Security Score (FSS) was calculated as in equations (1) and (2).

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

where PC_{jk} is the kth component for jth respondent household.

f_k^l is the factor loading of the kth component for the lth indicator.

X_j^l are factors of jth respondent households

$$FSS_j = \sum_{k} V_k \left(PC_{jk} \right) \tag{2}$$

FSS_j is the composite food security score of jth household.

V_k is the variance accorded by the kth principal component.

FSS is used to construct the FSI (equation (3)), and the scale ranges from 0 to 1.

$$FSI_j = \frac{FSS_j - FSS_{min}}{FSS_{max} - FSS_{min}} \tag{3}$$

where FSI_j is the food security index of jth household.

FSS_j is the food security score of jth household.

FSS_{min} is the minimum value of the food security score in the sample.

FSS_{max} is the maximum value of the food security score in the sample.

5.2. Empirical model: beta regression

The factors that determine the food security of flood-prone rural households could be modeled as the FSS (dependent variable) as a function of factors, viz., demographic, social, economic, physical and flood factors. The respective major factors consist of a few subfactors. A total of 18 subfactors constituted all the major factors. The independent variables (subfactors) are defined in Table 2, and they also provide the expected sign of the estimated coefficients. The model is explained in equation (4).

$$FSS_j = \propto + \beta_i X_{ij} + u_j \tag{4}$$

where FSS_j is the composite food security score of the jth household, X_{ij}denotes the variables (subfactors) under the adaptive capacity and exposure dimensions, and β_i denotes the respective coefficients. In this model, the FSI is a continuous variable in an interval (0,1) and is related to other variables in a regression structure. Therefore, instead of normal regression, we used a beta regression model [73]. The beta regression model is based on the beta density distribution in terms of the mean and parameters. The parameters of the model are estimated using Maximum Likelihood (ML). We use the betafit package in Stata to implement the model. We also estimated the average marginal effect using margin commands. Unlike the coefficient estimated using the model, Average Marginal Effects (AME) could be interpreted directly. In the case of a continuous variable, AME would be inferred as an additional unit of increase in the variable increasing the food security score by the level of the coefficient (similar to the interpretation of regression coefficients). In the case of dummy variables, the interpretation should be made with caution, as the likely change is from 0 to 1, and the coefficients are inferred as percentage changes.

Table 2
Explanation of subfactors used in the regression analysis.

Major factors	Subfactors	Variable type	Explanation	Signs
Demographic	Family type	Dummy	1 if the household is joint family and 0 if the household is nuclear family	(+)
	Head of household	Dummy	1 if the household head is female, otherwise = 0[$].	(−)
	Household head's age	Continuous	Age of the head of the household in years	(+)
	Literacy of the mother	Dummy	1 if the mother/female responsible for cooking is literate, otherwise = 0	(+)
	Social caste	Dummy	1 if household members belong to socially backward caste, otherwise = 0	(−)
Social	School access	Dummy	1 if household has access to school, otherwise = 0	(+)
	Access to informal money lenders	Dummy	1 if household has access to informal money lender, otherwise = 0	(−)
	Borrowing of money from kin	Dummy	1 if household borrows money from kin during crisis, otherwise = 0	(+)
Economic	Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)[a]	Dummy	1 if any of the household member joined MGNREGA, otherwise = 0	(+)
	Migration	Dummy	1 if household has at least one migrant member, otherwise = 0	(+)
	Bank access	Dummy	1 if household has access to bank, otherwise = 0	(+)
Physical	Housing structure	Dummy	1 if household has a permanent house, otherwise = 0	(+)
	Durable assets	Continuous	Number of durable assets in a household	(+)
Flood	Loss of property	Dummy	1 if household reports any property loss (livestock, house, durable assets) due to flood during the period between 2009 and 2014, otherwise = 0	(−)
	Stress	Dummy	1 if household reports any kind of stress due to flood, otherwise = 0	(−)
	Variation in average rainfall	Dummy	1 if household reports any variation in average rainfall during the period between 2009 and 2014, otherwise = 0	(−)
	Income earning environment deterioration	Dummy	1 if household reports income earning environment deterioration due to flood/climate change, otherwise = 0	(−)

[a] Government of India's employment programme for rural people.

6. Results and discussions

6.1. Household food security: FSI

We constructed the FSI, which reflects the portfolio of food security dimensions. The initial step in the FSI construction was to run polychoric PCA on the dataset of eleven indicators. The number of factors selected was based on the eigenvalue criterion, i.e., factors with eigenvalues greater than one were selected. Based on this criterion, the total number of components selected was four, and these four components explained 76.67% of the total variance. The first component (C1) had an eigenvalue of 4.393 and explained 39.94% of the variance. The second (C2) and third (C3) components had eigenvalues of 1.77 and 1.24, respectively. C2 explained 16.13% of the variance, and C3 explained 11.26% of the variance. A total of 9.34% of the variance was explained by the fourth component (C4), which had an eigenvalue of 1.03.

The results of the polychoric PCA are portrayed in Table 3. In a PCA framework, the correlation between a component and the indicators is called a factor loading and reveals the information shared by the indicators and components [62]. The proportion of the variance of each indicator explained by the component is shown by the square of the loadings [74]. The highest factor loading of each indicator was used for the construction of FSS, as in equation (2). Indicators such as dependence on family farms for food, agricultural land area, yield loss, crop diversification, and water access problems had the highest loadings in the first component. In the second component, monthly household expenditure on food, adequate food throughout the year, and livestock numbers had the highest factor loadings. Access to the PDS and malnutrition issues had their maximum loadings in the third component. Regarding the fourth component, the maximum loading was found with the instability of the food supply indicator. Although PCA provides information on the hidden correlation among various variables, the prime aim of PCA in this research was to generate weights for the creation of the FSI [75].

Table 3
Polychoric PCA components.

Food security dimension	Indicators	Components[a]			
		C1	C2	C3	C4
Food availability	Household food expenditure	−0.064	**0.874**	−0.117	0.198
	Adequate food throughout the year	0.004	**0.887**	0.165	−0.186
	Dependence on family farm for food	**0.980**	0.071	−0.101	0.003
Food access	Cultivated land area	**0.705**	0.053	0.239	0.327
	PDS access	−0.275	0.143	**0.652**	0.005
	Livestock	0.325	**0.396**	−0.232	−0.193
Food stability	Crop/yield loss	**0.937**	−0.042	−0.135	−0.051
	Instability of food supply	−0.014	−0.042	0.008	**0.940**
	Crop diversification index§	**−0.921**	0.013	0.129	0.191
Food utilization	Water access problems	**0.970**	0.018	−0.111	0.006
	Malnutrition issues	0.075	−0.149	**0.761**	0.018

[a] Bold figures indicate the uppermost component loading.

Bartlett's test of sphericity: Chi-square: 84.820 ($P < 0.0001$), df: 65.

The FSI ranged from 0 (least food secure) to 1 (most food secure), and based on that, the households were divided into four quartiles. The first quartile (0–0.250) consisted of 13% of households. The second (0.251–0.5) and third quartiles (0.51–0.75) comprised 57% and 27% of households, respectively. Only 3% of households belonged to the fourth quartile (0.751–1.0).

6.2. Determinants of household food security: multiple regression analysis

We analyzed the impact of various factors, viz., demographic, social, economic, physical and flood factors, on the food security of rural households. The estimated coefficients of the beta regression model are portrayed in Table 4. The average marginal effect for variables was calculated (Table 4). The marginal effects show how the outcome changed for each change in the independent variable. Marginal effects are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable from the mean [76].

6.2.1. Impact of household demographic characteristics on food security

The food security of households can be affected by a number of

demographic characteristics. Among the subfactors of demographic profile, family type had a positive and significant influence on rural household food security. In India, joint family systems are common, especially in rural areas. In a joint family, members live together and share all expenses and work with the other members of the family. The joint family system acts as a shock-absorbing approach for several household issues [77]. The decisions in the households are made jointly by the elderly members of the family. Many joint families consist of more than one earning member, and these earning members often contribute significantly to the overall economic situation of the household [78]. As the economic situation of a household enhances, household may spend more money on food items. In joint families, the ownership of assets and lands takes place on a joint basis, which avoids the fragmentation of family land holdings. The fragmentation of land holdings may result in a small output of agricultural products or may even lead to the complete cessation of agriculture itself. This will ultimately create food security issues for households in rural areas.

The food security of rural households may likely be influenced by the head of the households. Our study showed that the heads of households had a negative and significant influence on food security. In the sample households, only 25% of households had females as household heads. The majority of the Indian household heads are males. Females may become the head of households due to events such as the death of male heads, family conflicts and disruption and migration of male heads [79]. A study of [80] noted that food security issues were higher in female-headed households than in male-headed households. This was due to lower literacy levels, wage disparity in the labor markets, limited land ownership, restrictions on mobility and responsibilities for children and household maintenance. The household head's age affects the food security of households. The household head makes all important decisions in the family; therefore, age is quite important with regard to the food security of households. As the age of a household head increases, it is assumed that he or she could acquire more knowledge about the social and physical environments and greater experience of farming activities [81]. Older household heads are more risk averse, and their chance of becoming more food secure increases with age.

Table 4
Impact of various subfactors on household food security.

Major factors	Subfactors	Beta regression coefficients	Marginal effects
Demographic	Family type	0.401***	0.094***
		(0.095)	(0.022)
	Head of household	−0.283***	−0.065***
		(0.104)	(0.024)
	Household head's age	0.009**	0.002**
		(0.004)	(0.001)
	Literacy of the mother	0.155	0.035
		(0.146)	(0.033)
	Social caste	0.017	0.004
		(0.091)	(0.021)
Social	School access	0.167**	0.038**
		(0.080)	(0.018)
	Access to informal money lender	0.032	0.007
		(0.088)	(0.020)
	Borrowing of money from kin	−0.091	−0.021
		(0.080)	(0.018)
Economic	MGNREGA	0.224**	0.512**
		(0.088)	(0.020)
	Migration	0.512***	0.118***
		(0.109)	(0.025)
	Bank access	−0.118	−0.027
		(0.113)	(0.026)
Physical	Housing structure	0.108	−0.027
		(0.086)	(0.026)
	Durable assets	0.252***	0.058***
		(0.037)	(0.008)
Flood	Loss of property	−0.199**	−0.045**
		(0.087)	(0.020)
	Stress	−0.012	−0.003
		(0.075)	(0.017)
	Variation in average rainfall	0.085	0.020
		(0.078)	(0.018)
	Income earning environment deterioration	0.075 (0.074)	0.017 (0.017)
	Constant	−1.961***	
		(0.264)	
	ln_phi	2.673***	
		(0.093)	

Standard errors in parentheses; ***p < 0.01, **p < 0.05.

6.2.2. Impact of household social characteristics on food security

Societal integration, social networks and institutions are considered important actors in improving household food security, especially during crises. The variable 'access to school' was significant and had a positive coefficient, indicating that access to school can improve the food security condition of households. Although schools do not have a direct link with the overall food security of households, they are helpful in increasing the food security of children who are attending schools. It is noteworthy that the Government of India introduced the 'mid-day meal scheme' at schools in 1995. This scheme was initiated to improve the nutritional status of school-going children. This scheme provides free cooked lunches to children at school, which in turn helps poor children to be healthy and to regularly attend school. Children belonging to disadvantaged sections of society do not have access to daily food with adequate nutritional intake. The mid-day meal scheme acts as a path for human development, and it delivers food to approximately 120 million school-going children, making it the world's largest school feeding program.

6.2.3. Impact of household economic characteristics on food security

[82] mentioned the positive relationship between the MGNREGA and food security. We also found that employment under the MGNREGA can improve the food security condition of rural households. The MGNREGA was implemented in 2005 and is the largest work guarantee program in the world. The primary objective of this programme is to provide 100 days of wage employment per year with a statutory minimum wage to any adult from a rural household who is willing to do unskilled manual labor [83,84]. The employment opportunities provided through the MGNREGA in rural areas enhance the purchasing power of the rural population [85], which ultimately leads to the food security of households.

We found a significant and positive relationship between migration and household food security. The majority of households in the studied villages depend on agriculture for their income. Depending on agriculture alone is risky, as these areas are highly prone to floods. Households diversify their incomes by working as daily laborers, migrating to nearby cities/states and running small-scale businesses. Migration has become a key element of livelihood strategies in many developing countries, as remittances are positively tied to the wellbeing of migrant-sending households [86]. Poor households spend their major share of income on food [87]. Migration can generate a positive direct income effect through remittances sent back home [88]. Household income is one of the most important factors affecting food security and hunger, as hunger rates decline sharply with an increase in income [89]. It is also noted that cash is essential to purchase essentials such as salt, oil and preferred foods that are not home produced or bartered [90].

6.2.4. Impact of household physical characteristics on food security

Household assets have a significant role in food security, as they improve households' ability to withstand unexpected changes. Households' capability to manage food security problems depends on their access to different assets [91]. During extreme climatic events, selling durable assets is a common coping strategy among rural poor populations [92]. Durable assets are bought during wealthy periods and are sold during negative income shocks to buy food. Thus, these assets act as an instrument for safeguarding household food security during climatic

extremes. We hypothesized that rural households with a greater number of physical assets are more food secure. Our results also showed a positive and significant effect of the number of durable assets on the food security of rural households. Assets are defined as the stocks of resources that households can convert directly or indirectly into means of survival [93]. [43] mentioned in their study that an increase in the number of various assets as part of food security initiatives enhanced households' ability to survive sudden economic crises or seasonal food shortages that threaten their food security. Durable assets have high liquidity and therefore can be easily converted into cash.

6.2.5. *Impact of flood on food security*

Floods have implications for the food security of rural populations through various direct and indirect effects. The direct impact on food security comes from damage to standing food crops, stored grains and livestock, while the indirect impacts include, inter alia, low purchasing power, compromised health, social unrest and domestic violence [94, 95]. Every year, floods continue for approximately 5–10 days and cause damage to life and property in the study area. The results presented in the above subsections indicate the indirect impacts of floods/flood vulnerability on the food security situation within the studied region, whereas the reported direct impact of floods on the food security situation among respondents has its own significance. The results in Table 4 show that loss of property due to the onset of flood events significantly undermined the food security status of households. The loss of property due to floods leading to disturbed food security conditions seemed to have an indirect impact; however, the loss of property included losses to livestock, crops and stored grains along with durable assets that have a strong and direct bearing on the food security of the region. The marginal effect of this variable was also significant and further complemented the role of property loss on the food security situation of the region. Specifically, a 1% increase in the probability of loss of property due to floods decreased the food security status by 4.5%. Additionally, stress due to floods had an expected a priori sign, showing a negative relationship with the food security status of households; however, the relationship was statistically non-significant. Variables related to variation in average rainfall and the deterioration of the income earning environment due to flood incidence were shown to have diminutive/nonsignificant impacts on households' food security status. These findings are indicative of the impact that floods have on food security by destroying/disturbing asset bases and household inventories. The one significant variable related to loss of property speaks of the increased impact of floods on households' food availability and consumption along with compromised nutrient uptake. Other variables under the major factor category of 'flood' are not as important in influencing people's food security, as their marginal effect was equal to or less than 4%. In this regard, increased flood vulnerability leads to increased property loss, which then influences the level of food security among the masses. There are multiple implications of this finding. It points toward the necessity of protecting households' assets, which act as a cushion in the wake of disasters in many alternative ways. Another option is to expand opportunities for safeguarding households' durable assets through insurance or related mechanisms.

7. Conclusions

Floods deteriorate the normal functions of human life, affecting livelihoods, agricultural production, economic activities, water and health care. All these factors have an impact on the food security of a household. Most of the studies on food security have concentrated on food expenditures, food consumption patterns and nutritional security. However, astonishingly little former research has directly studied the factors that contribute to food consumption and nutritional security.

We analyzed food security with an emphasis on the elements that affect the expenditure and consumption patterns of food and nutritional security using a composite index. The state of Odisha in India was selected for our research, as this state is representative of regions that are underdeveloped and that depend on subsistence agriculture. The majority of the people in this state live in poverty and hunger and face recurrent floods. The results of our study proved that the majority of flood-affected rural households had food security issues. This situation implies a range of policy interventions to overcome further increases in food insecurity level, which may become more intensified due to recurrent floods. We also investigated the factors that influence the food security of households, and the average marginal effects for each of the significant variables were also calculated. The results showed that a joint family structure, education, the MGNREGA and physical assets positively influence food security. Our study noted that households that are food secure are those with alternative employment and social support. Efforts to ensure food security should consider providing additional employment through existing employment guarantee programmes such as the MGNREGA to augment food security. This would mean a policy discourse from relief to coping mechanisms against floods. Employment opportunities in fields other than agriculture should be created. These will provide an alternative income to households even in the case of agricultural failure. Household exposure to floods affects food security directly or indirectly. Community-assisted local flood disaster management schemes and food security assurance plans during flood periods need to be developed and implemented. Systemic changes need to be carried out by different stakeholders, especially in the financial sectors and government institutions, mainly working on social protection and welfare administration to decrease the spatial and temporal severity of impacts.

We found that there are substantial food security issues in the least developed and most flood-prone rural regions, and it is essential to address the base-level indicators that lead to food security. Our study is a representative study on food security performed using a broader approach than previous studies, and we can generalize that the food security of similar regions may be the same or worse. However, we need a concrete study about the food security of other similar regions that are conducted in an identical manner to validate our results, which would provide insights into future research endeavors.

Declaration of competing interest

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

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