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Is Food Security in Uttarakhand Sustainable?—Evidence from a District-Level Study

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ABSTRACT

Background: In order to feed the world's nine billion people by the year 2050, food production must be greatly boosted. This necessitates investigating the long-term sustainability of food security. There have previously been attempts to develop indices for gauging the sustainability of food security. However, an index that assesses trade-offs related to the sustainability of food security in addition to absolute measures is necessary for a thorough understanding. A number of variables, including income, population, and climate change, impact food security. In addition to being at risk from climate change, Uttarakhand is also dealing with the problem of migration. In order to evaluate the sustainability of food, a new Sustainable Food Security Trade-off Index (SFSTI) is created in the current study in the special context of Uttarakhand. Methods: The new Human Development Index (HDI) methodology served as the foundation for the creation of SFSTI. Data covering 52 years, from 1966 to 2017, is used to evaluate the index. It makes use of the trade-offs between the positive and negative indicators found in the food security dimensions of accessibility and availability. Results: The results revealed that none of the districts could cross the 0.5 mark on normalization scale of SFSTI, indicating low sustainability of food security. Pithoragarh achieved the highest score of 0.45 on the index, while Tehri Garhwal and Uttarkashi obtained the lowest scores of 0.29. Sustainable food security can be achieved with the twin goals of sustainable intensification and sustainable healthy diets. A food system supporting food security, using natural and human resources optimally, being acceptable culturally and accessible, environmentally acceptable, economically viable, fair, and providing the consumers with nutritionally adequate, safe, healthy and affordable food for present and future generations can ensure sustainability.

Key words: climate change, food security, Himalaya, migration, sustainability

INTRODUCTION

Food security exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food. The failure of this conventional notion of food security to take sustainability into account necessitated the discussion of "sustainable food security". The concept of sustainable development was used to incorporate the sustainability of food security into international talks. According to the United Nations (1987), sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Speth first introduced the idea of sustainable food security in 1993 (Speth, 1993; Findiastuti et al., 2017). The idea of sustainability is expanded to include sustainable food systems in the current situation. According to Capone et al. (2014), a sustainable food system promotes food security, makes the best use of human and natural resources, is acceptable in terms of culture and accessibility, is environmentally acceptable, economically viable, and equitable, and offers consumers safe, healthy, and affordable food that is safe, nutritious, and affordable for both current and future generations. The food systems will need to greatly boost food production for a population expected to reach 9 billion by 2050, provide economic opportunities for rural people who rely on agriculture, and reduce environmental effects in order to fulfill global food demands. Thus, it is essential to investigate food security sustainability and develop techniques to evaluate their efficacy.

The three facets of sustainability are environmental, social, and economic. Environmental, economic, and social sustainability should all be taken into consideration while achieving the objectives of food security, which include food production, job creation, and the supply of basic amenities (MSSRF and WFP, 2004).

The significance of providing enough food without endangering the environment or the natural resources required for future production was emphasized by MSSRF and WFP (2004), who emphasized two aspects: Present Security and Future Sustenance. Numerous studies have been conducted on the food security index at both the national and regional levels. Kumar et al. (2017) used the composite Z-index technique to determine the food security index for 13 Indian states. Sahu et al. (2017) and Kumar et al. (2020) evaluated food security at the regional level, whereas Kumar and Ayappan (2014) and Pandey (2015) evaluated food security at the national level.

According to Berry et al. (2015), sustainability is an essential precondition for guaranteeing long-term food security. The 'Atlas of Sustainable Food Security', created by the World Food Program and MSSRF in 2004, is noteworthy for its substantial contribution to this topic, especially when considering the Indian context. Singh et al. (2021) used the MSSRF and WFP (2004) methodology to analyze food security sustainability at the district level in Uttar Pradesh, India. On the one hand, studying the sustainability of food security requires an absolute index. However, trade-offs that impact food security and sustainability must also be taken into account. Given that a number of factors, including population, income, migration, and climate change, impact the sustainability of food security, it is imperative to take trade-offs into account. Food security is significantly impacted by climate change. Rainfed crops lose a lot of output due to extreme climate changes (Kumar and Upadhyay, 2019; Pampori and Sheikh, 2023). The majority of farmers in Uttarakhand, a state heavily reliant on agriculture and made up of both mountainous and plain regions, fall into the most vulnerable group, known as the marginal category. It has been acknowledged that the Himalayan region is a particularly sensitive area where the effects of climate change have been felt in recent years (Balasubramanian & Kumar, 2014). Furthermore, Uttarakhand continues to face the challenge of significant migration (Sethi, 2024). Incomes and the security of food and nutrition are often positively impacted by migration (Abebaw et al., 2020; Zezza et al., 2011). However, it is also leading to the rise of ghost villages in Uttarakhand's rural districts. In light of the aforementioned considerations, this study has created a unique method that provides a trade-off index for long-term assessment utilizing time-series data in order to evaluate trade-offs influencing food security in various districts of Uttarakhand.

METHODOLOGY

Construction of Sustainable Food Security Trade-Off Index

The Sustainable Food Security Index was created by the WFP and MSSRF in 2004. A list of indicators utilized by the MSSRF and WFP (2004) under the various components of the Sustainable Food Security Index has been provided by Singh et al. (2021). Table 1 provides the list.

Table 1. Components of Sustainable Food Security Index as given by MSSRF and WFP (2004).

Component	Sub-component	Indicators	Relation with sustainable food security
Sustainable food availability	Food availability security	Cropping intensity	Positive
		Change in net sown area	Positive
		Food grain production per capita	Positive
		Irrigation intensity	Positive
		Fertilizer consumption (NPK)	Positive
		Population density	Negative
		Milk productivity	Positive
	Food availability sustenance	Per capita forest cover	Positive
		Degraded area to geographical area	Negative
		Leguminous crops in gross cropped area	Positive
		Unexploited ground water for the future	Positive
		Rate of change in annual mean temperature	Negative
		Coefficient of variation of monthly mean rainfall	Negative
Sustainable food access	Food access security	Below poverty line population	Negative
		Non-agricultural workers to total workers	Positive
		Non-worker population	Negative

		Number of milch animals per ‘000 population	Positive
		Cross-bred adoption rate	Positive
		Buffalo to Indigenous cattle ratio	Positive
		Small and marginal farmers per ‘000 population	Negative
	Food access sustenance	Average size of holding	Positive
		Livestock density	Negative
		Non-crop agricultural workers	Positive
		Landless labour households to total households	Positive
		Instability in cereal production	Negative
Food utilization	Food utilization security	Safe drinking water	Positive
		Infant mortality rate	Negative
		Health infrastructure	Positive
		Female literacy rate	Positive

The index was created by MSSRF and WFP (2004) using Principal Component Analysis (PCA). From their list of indicators, significant indicators have been chosen for the current study based on their significance and their positive or negative relationship to sustainable food security. The new Human Development Index (HDI) methodology (Klugman et al., 2011) served as the foundation for the construction of the new index, which is based on the trade-offs related to the sustainability of food systems. Figure 1 shows the conceptual framework of SFSTI.

$$SFSTI = \sqrt[3]{(N\_SFAvI.N\_SFAcI.N\_FUI)}$$

where, SFSTI = Sustainable Food Security Trade-off Index N_SFAvI = Normalized Sustainable Food Availability Indicator or normalized SFAvI, N_SFAcI = Normalized Sustainable Food Accessibility Indicator or normalized SFAcI, N_FUI = Normalized Food Utilization Indicator or normalized FUI.

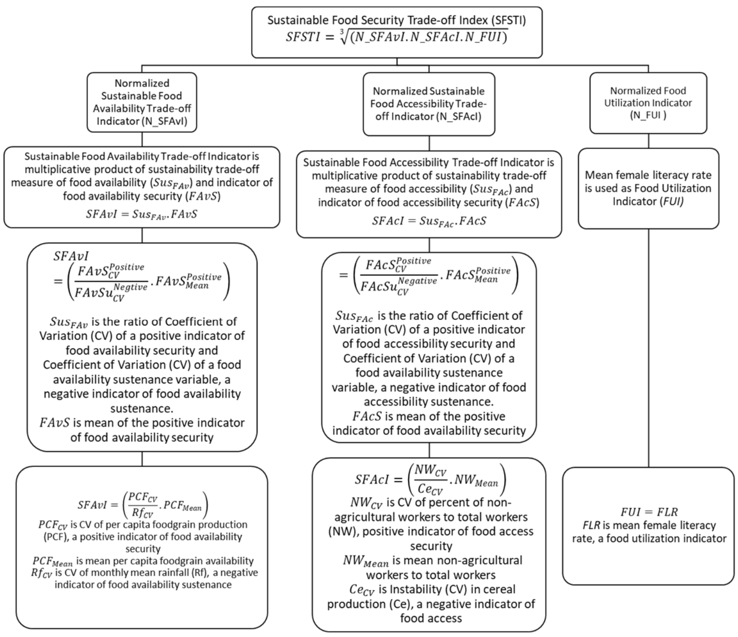

Fig. 1. Conceptual framework of Sustainable Food Security Trade-off Index.

The HDI methodology is a suitable approach since it penalizes for inequality across dimensions through geometric mean; that is, a lower geometric mean will result from significant inequality across dimensions. The arithmetic mean, on the other hand, treats all dimensions equally and makes the assumption that a change in one may be made up for by an equivalent rise in another, resulting in the same level of performance.

In contrast to the MSSRF and WFP (2004) Sustainable Food Security Index, the current study's SFSTI index is built by examining 52 years of data, since it is necessary to evaluate long-term sustainability trade-offs. The following normalization formula, which was used in the creation of the new HDI, is applied to the indicators:

$$\frac{x - x_{min}}{x_{max} - x_{min}}$$

where, x_{min} is the minimum value and x_{max} is the maximum value.

Construction of Indicators of SFSTI

SFAvI and SFAcI are the multiplicative products of (1) sustainability indicator and (2) Availability/accessibility indicator as follows:

$$\mathrm{SFAvI} = \mathrm{Sus_{FAv}}.\mathrm{FAvS}$$

$$\mathrm{SFAcI} = \mathrm{Sus_{FAc}}.\mathrm{FAcS}$$

where, $\mathrm{Sus_{FAv}}$ is the sustainability trade-off measure of food availability

FAvS is an indicator of food availability security.

$\mathrm{Sus_{FAc}}$ is the sustainability measure of food accessibility.

FAcS is an indicator of food accessibility security.

Both FAvS and FAcS are amplified by their respective sustainability measures to compute SFAvI and SFAcI, respectively. The sustainability measure, $\mathrm{Sus_{FAv}}$ measures the extent to which the variability or instability in the negative indicator of food availability sustenance is reflected in the variability of the positive indicator of food availability security. Similarly, $\mathrm{Sus_{FAc}}$ the extent to which the variability or instability in the negative indicator of food accessibility sustenance is reflected in the positive indicator of food accessibility security.

Since there is no sustenance counterpart indicator or trade-off involved with Food Utilization, therefore, the food utilization indicator is taken singly.

The sustainability measures and SFAvI and SFAcI are expanded as follows:

$$\mathrm{SFAvI} = \left(\frac{\mathrm{FAvS_{CV}^{Positive}}}{\mathrm{FAvSu_{CV}^{Negtive}}}.\mathrm{FAvS_{Mean}^{Positive}}\right)$$

$$\mathrm{SFAcI} = \left(\frac{\mathrm{FAcS_{CV}^{Positive}}}{\mathrm{FAcSu_{CV}^{Negative}}}.\mathrm{FAcS_{Mean}^{Positive}}\right)$$

where, $\mathrm{FAvS_{CV}^{Positive}}$ is Coefficient of Variation (CV) of a positive indicator of food availability security $\mathrm{FAvSu_{CV}^{Negative}}$ is Coefficient of Variation (CV) of a food availability sustenance variable, a negative indicator of food availability sustenance $\mathrm{FAvS_{Mean}^{Positive}}$ is mean of the positive indicator of food availability security $\mathrm{FAcS_{CV}^{Positive}}$ is Coefficient of Variation (CV) of a positive indicator of food access security $\mathrm{FAcSu_{CV}^{Negative}}$ is Coefficient of Variation (CV) of a food access sustenance variable, a negative indicator of food access sustenance $\mathrm{FAcS_{Mean}^{Positive}}$ is mean of the positive indicator of food access security

If the value of the ratio of CV of the numerator (positive indicator) and CV of the denominator (negative indicator) is greater than 1, it indicates that the variability in the negative indicator causes high variability in the positive indicator. If it is 1 or less than 1, it indicates that the variability in the negative indicator is not causing equivalent variation in the positive indicator. Since the positive indicators of both food availability security as well as food access security are moving in a positive direction, growing with time except for short-term shocks, therefore, a value greater than 1 of sustainability measures is interpreted to signify a sustainable system. Multiplying the ratio of CV's with the mean gives the true value of the sustainable food security indicator, as it reflects the long-term impact of sustainability/instability in the mean value of the indicator under consideration as the ratio escalates/brings down the mean value.

The indicators are chosen from the list of indicators given in Table 1. They are chosen on the basis of trade-offs or relationships operating behind sustainable food security, which are posited as follows: The operational trade-offs or relationships are related to 'sustainable food availability' and of 'sustainable food accessibility'. The sustainable food availability relationship is between 'per capita foodgrain production' and 'monthly mean rainfall'. Per capita foodgrain production is a suitable indicator of food availability security as it involves foodgrain production as well as adjustment for increasing population. The coefficient of variation of monthly mean rainfall was found by computing averages and standard deviation of mean monthly rainfall first of all the months over the study period, and then computing the coefficient of variation [(Standard deviation/Mean) × 100] for the period. The relationship between 'per capita foodgrain production' and 'monthly mean rainfall' can be described as follows: when there is a high degree of variability in rainfall, it is expected that foodgrain production will exhibit greater levels of instability. High or low variability in rainfall patterns can cause either water excess or water stress. Water excess can lead to waterlogging, soil erosion, nutrient leaching, and increased disease and pest incidence, whereas water stress can create drought conditions, leading to reduced crop yields, crop failures, and even famine in extreme cases. These conditions can negatively impact crop growth, reduce yields, and damage crops, ultimately affecting per capita foodgrain production. Hence, the trade-off.

The Sustainable Food Accessibility relationship is between 'ratio of non-agricultural workers to total workers' and 'instability in cereal production' (a negative indicator of food access sustenance). Non-agricultural workers to total workers refers to the proportion of individuals employed in non-agricultural sectors to the total workforce in an economy. This indicator reflects the level of diversification and development in a region's economy, as higher proportions of non-agricultural workers are often associated with industrialization, urbanization and higher income and food accessibility. On the other hand, instability in cereal production refers to the variability or fluctuations in the annual production of cereal crops. This instability can be influenced by factors like weather conditions, pests, diseases, and market fluctuations. Fluctuations in cereal production can have significant implications for food security, prices, and overall economic stability. The trade-off between these two indicators (ratio of non-agricultural workers to total workers and instability in cereal production) arises from the fact that as an economy becomes more industrialized and the proportion of non-agricultural workers increases, there may be a shift away from agriculture towards other sectors. This shift can lead to a decrease in the agricultural labor force and potentially affect cereal production. As more labor is drawn into non-agricultural sectors, there might be a reduced focus on agricultural activities, including investments in infrastructure, research, and development, which can also contribute to instability in cereal production. Conversely, as the instability in cereal production increases, there are more unstable incomes and agricultural workers are forced to migrate to non-agricultural sectors. The movement of workers from agriculture to non-agricultural sectors may be a topic of concern, especially from the present and future domestic food availability perspective, but it also presents an opportunity for the creation of improved prospects and higher incomes for those workers, leading to higher accessibility.

Female literacy rate is a suitable food utilization indicator as it plays a significant role in nutrition security. Higher levels of female literacy have been associated with improved nutrition outcomes at both individual and household levels. Female literacy empowers women with knowledge and information about nutrition, health, and hygiene practices and enables them to make informed decisions regarding their own diet and the nutrition of their families. When women are literate, they are more likely to have a voice in determining the nutritional needs of their families and allocating resources accordingly, ensuring adequate food intake and balanced diets for all household members. Female literacy has a long-term impact on food and nutrition security by breaking the intergenerational cycle of malnutrition. Educated women are more likely to have healthier pregnancies, practice proper infant and young child feeding, and provide a nurturing environment for their children's growth and development (Ahmed et al., 2012; Smith and Haddad, 2015).

Substituting the variables in the indicators,

$$\mathrm{SFAvI} = \left(\frac{\mathrm{PCF_{CV}}}{\mathrm{Rf_{CV}}}.\mathrm{PCF_{Mean}}\right)$$

$$\mathrm{SFAcI} = \left(\frac{\mathrm{NW_{CV}}}{\mathrm{Ce_{CV}}}.\mathrm{NW_{Mean}}\right)$$

$$\mathrm{FUI} = \mathrm{FLR}$$

$\mathrm{PCF_{CV}}$ is CV of per capita foodgrain production (PCF), a positive indicator of food availability security.

PCF is mean per capita foodgrain availability $\mathrm{Rf_{CV}}$ is CV of monthly mean rainfall (Rf), a negative indicator of food availability sustenance $\mathrm{NW_{CV}}$ is CV of percent of non-agricultural workers to total workers (NW), positive indicator of food access security NW is mean non-agricultural workers to total workers $\mathrm{Ce_{CV}}$ is Instability (CV) in cereal production (Ce), a negative indicator of food access sustenance FLR is mean female literacy rate, a food utilization indicator.

The value of 1 for the Sustainability Measure of food availability ($\frac{\mathrm{PCF_{CV}}}{\mathrm{Rf_{CV}}}$) means the variability of rainfall is perfectly reflected in the per capita foodgrain availability variability. If the value moves towards zero, it means that the variability of rainfall is not getting reflected in per capita foodgrain variability due to the current low level of irrigation facilities, absence of suitable technological measures like rainwater harvesting, etc. The values exceeding 1 show that the rainfall variability gets amplified in terms of per capita foodgrain availability variability in these districts due to interventions such as the adoption of technology and management practices for sufficient food production, climate change adaptation, etc.

The value of 1 for the Sustainability measure of food accessibility ($\frac{\mathrm{NW_{CV}}}{\mathrm{Ce_{CV}}}$) means the cereal instability or cereal variability is perfectly reflected in the non-agricultural workers percentage (out of total workers) variability. If the value moves towards zero, it means that the cereal variability is not getting translated to the non-agricultural workers percentage (to total workers) variability and the workers stay in agricultural occupation. This may signify disguised unemployment in agriculture. The values exceeding 1 show that the cereal variability gets amplified in terms of the non-agricultural workers percentage (to total workers) variability in these districts due to the current non-availability of employment or self-employment opportunities in agriculture sector, poor extension facilities, crop damage by pests, crop raiding by wild animals, poor availability of irrigation facilities, etc. Inability to prevent migration from agriculture sector is a matter of concern. However, non-agricultural workers percentage (to total workers) in the current scenario is a positive indicator and signifies better incomes and hence better food accessibility and affordability, especially for the urban areas.

The maximum and minimum values for normalization formulae are as follows: The minimum value for SFAvI, SFAcI and FUI each is 0. The maximum value for SFAvI is 350.4 kg per annum, as the recommended dietary allowance for foodgrains according to NIN (2011) is 175.2 kg per annum. Assuming that an equal quantity is retained for storage, the value becomes 350.4 kg per annum, which is twice of 175.2 kg per annum. The maximum values for SFAcI and FUI are 100 each, as these are percentages.

Data Source

In this study, the apportioned district-level dataset compiled by ICRISAT and TCI (ICRISAT-TCI, 2015) for the period 1966–2017 was used as the data available for a longer period. Missing values were linearly interpolated. The apportioned dataset is available for 1966 district boundaries. The districts in Uttarakhand with the 1966 district boundaries were 8 in number, namely, Almora, Chamoli, Dehradun, Pauri Garhwal, Nainital, Pithoragarh, Tehri Garhwal and Uttarkashi.

Study Area

To conduct this study, Uttarakhand (Figure 2) was selected as the study area due to its representation of both plains and hills. The hills constitute 86 per cent of the total area of Uttarakhand, whereas the plains constitute 14 per cent (DES, 2021). Uttarakhand, situated in the Central Himalayan region, spans an area of 53,483 km^2 (DES, 2021). The area exhibits diverse climatic zones, with sub-tropical conditions at lower altitudes in the southern region and alpine or arctic conditions at higher altitudes in the extreme northern part. The primary livelihood in Uttarakhand is agriculture (Maikhuri et al., 2019). The state has experienced significant impacts of climate change, evident through unpredictable rainfall, rising temperatures, reduced snowfall, and an increasing occurrence of landslides and soil erosion, thus affecting food security. It cannot be argued with certainty that the effects of climate change on food security have been wholly negative because rising temperatures have caused some low-altitude crops to be grown at mid-altitudes as well. It has been hypothesized that evaluating the sustainability of food security for the districts of Uttarakhand will yield balanced scores on the sustainable food security trade-off index that account for variation.

For the purpose of assessment, it is also necessary to calculate the sustainability measures, sustainable food security trade-off index, and its components for the districts of Uttarakhand.

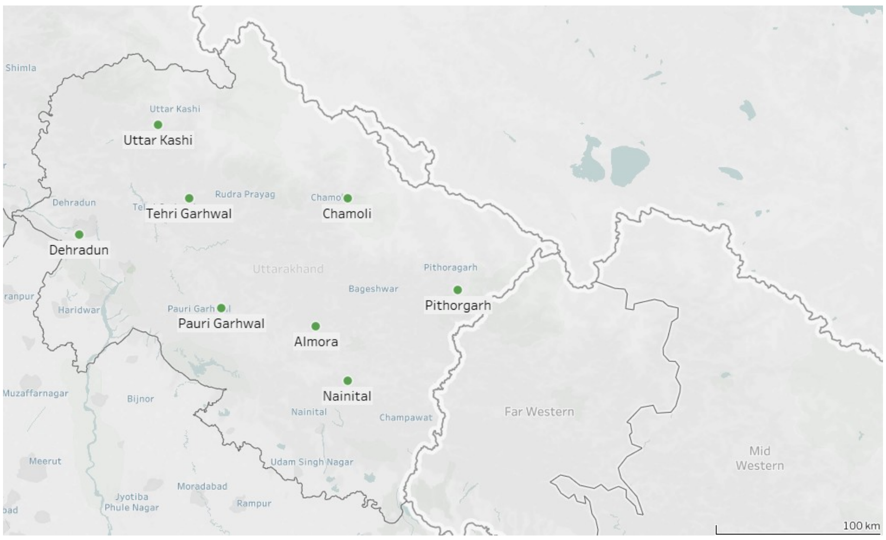

Fig. 2. Map showing the coordinate locations of Uttarakhand districts with old boundaries vis-à-vis new district boundaries. Note: New district borders are displayed in the backdrop, and the names of the districts are indicated in blue. Depending on their coordinates, the locations of the old districts are displayed in green.

RESULTS AND DISCUSSION

SFSTI and Its Components

The sustainability measures for food availability and food accessibility in the different districts of Uttarakhand are given in Table 2. The Sustainability Measure of food availability, which is the ratio of the coefficient of variation of per capita foodgrain availability to the coefficient of variation of rainfall, ranges from approximately 0.70 to 1.52. Tehri Garhwal district scored the highest on the sustainability measure for food availability with a value of approximately 1.52, while Pauri Garhwal district scored the lowest with a value of approximately 0.70. The value is less than 1 in Almora (0.90), Nainital (0.71) and Pauri Garhwal (0.70), indicating that there is scope to make food availability more sustainable in these districts by providing better technologies, extending knowledge of climate change adaptation, etc.

On the other hand, the Sustainability Measure of food accessibility, which is the ratio of the coefficient of variation of the percentage of non-agricultural workers out of total workers to the cereal instability, ranges from approximately 0.30 to 0.64. Pithoragarh district had the highest sustainability measure for food accessibility with a value of approximately 0.64, while Nainital district had the lowest with a value of approximately 0.30. All of the districts had values less than 1, which shows that while there is some variability in non-agricultural workers percentage (to total workers), the cereal instability is not being perfectly translated to variability in non-agricultural workers due to the presence of some incentives that retain workers in the agricultural sector. While migration to non-agricultural sector could be discouraged by creating enough opportunities in the agricultural sector, for the current situation, in general, the higher percentage of non-agricultural workers (to total workers) signifies higher incomes and hence higher affordability and accessibility.

Table 3 presents district-wise scores for the SFSTI and its components, namely, Normalized SFAvI, Normalized SFAcI, Normalized FUI, and the overall SFSTI. Figure 3 shows a radar pictorial of SFSTI and its indicators. Table 3 presents district-wise scores for the SFSTI and its components, namely, Normalized SFAvI, Normalized SFAcI, Normalized FUI, and the overall SFSTI. Figure 3 shows a radar pictorial of SFSTI and its indicators.

Table 2. Sustainability measures for the districts of Uttarakhand.

Districts	Sustainability measure of food availability	Sustainability measure of food accessibility
Almora	0.90	0.55
Chamoli	1.21	0.47
Dehradun	1.05	0.41
Pauri Garhwal	0.70	0.52
Nainital	0.71	0.30
Pithoragarh	1.17	0.64
Tehri Garhwal	1.52	0.35
Uttarkashi	1.06	0.48

Table 3. Sustainable food security trade-off index and its components.

District	Normalized SFAvI	Normalized SFAcI	Normalized FUI	Sustainable food security trade-off index (SFSTI)
Almora	0.41	0.32	0.31	0.34
Chamoli	0.46	0.25	0.30	0.33
Dehradun	0.25	0.35	0.47	0.34
Pauri Garhwal	0.27	0.34	0.35	0.32
Nainital	0.74	0.22	0.35	0.38
Pithoragarh	0.77	0.39	0.31	0.45
Tehri Garhwal	0.55	0.20	0.23	0.29
Uttarkashi	0.47	0.24	0.21	0.29

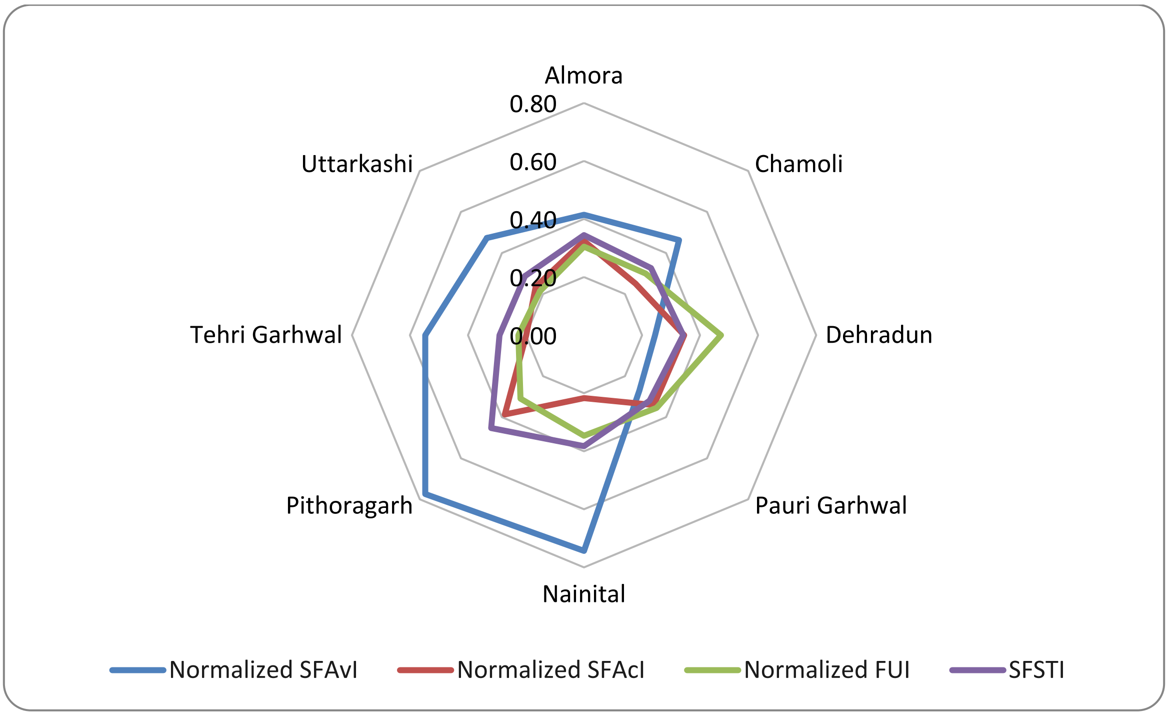

Fig. 3. Radar pictorial showing Sustainable Food Security Trade-off Index (SFSTI) and its indicators.

Pithoragarh scored the highest (0.77) on normalized SFAvI among all districts, showing high performance in the sustainable food availability dimension. However, Dehradun and Pauri Garhwal had the lowest scores (0.25 and 0.27, respectively), indicating challenges in maintaining a stable food resource base. Evidently, Pithoragarh has the highest per capita availability of two main components of the food basket, namely, pulses and vegetables, according to the Food and Nutrition Insecurity Atlas of Uttarakhand 2019–2020 (Srivastava et al., 2022).

Pithoragarh (0.39) and Dehradun (0.35) attained the highest scores on normalized SFAcI, signifying better food distribution systems and better access to nutritious food. On the other hand, Tehri Garhwal had the lowest score (0.20), indicating potential issues in accessibility to sustainable food resources. Notably, Dehradun has the lowest percentage of Below Poverty Line (BPL) families, whereas Tehri Garhwal has the highest. This corroborates the fact that high income indicates better food access and preparedness (Srivastava, 2023).

Dehradun scored the highest (0.47) on normalized FUI. It indicated better utilization of available food resources. However, Uttarkashi and Tehri Garhwal had the lowest scores (0.21 and 0.23, respectively), suggesting challenges in optimizing food utilization and assimilation and addressing potential issues with malnutrition and food loss.

Pithoragarh achieved the highest SFSTI score (0.45), reflecting better efforts in promoting sustainable food systems and ensuring access to nutritious food. According to the State of Nutrition of Uttarakhand, Pithoragarh is one of the best-performing districts (IFPRI, 2022). Conversely, Tehri Garhwal and Uttarkashi had the lowest SFSTI scores (both 0.29), indicating a need for focused interventions to improve food security and sustainability of food security in these districts. The number of pregnant anaemic women in Uttarkashi and Tehri Garhwal indicates that these districts have a particularly high burden, according to Uttarakhand's State of Nutrition profile. When compared to other interventions, the coverage of antenatal care interventions is low in both districts. Additionally, it is advised that the quality of interventions be ensured (IFPRI, 2022).

Most districts (Nainital, Pithoragarh, Tehri Garhwal, Uttarkashi, Almora, Chamoli) have high levels of sustainable food availability, but low levels of sustainable food accessibility and food utilization indicators, as seen in the radar figure. Initiatives are therefore needed to guarantee fair food distribution and to raise awareness of diets for appropriate food use. In particular, the migratory workers should be given better opportunities and affordable food access to improve the sustainability of food accessibility. In addition to programs for climate change adaptation and incentives to address migration and the rise of ghost villages, new employment possibilities should be developed in rural areas.

Attaining sustainable food security necessitates a more comprehensive approach beyond simply enhancing farm productivity and profitability while minimizing environmental harm. It extends beyond the boundaries of sustainable agriculture, twinning the objectives of household food security and sustainable agriculture. Both aspects are indispensable. To achieve sustainable food security, we must not only focus on the overall food supply but also consider factors such as income and land distribution, household livelihoods, dietary requirements, food distribution, and waste management. Also, addressing women's status and opportunities, fertility and population concerns, as well as the protection and restoration of the resource base is required for food production, encompassing terrestrial, aquatic, and climatic aspects. Taking these multifaceted factors into account is essential for establishing a sustainable food security framework (Aborisade and Bach, 2014).

According to Fan & Brzeska (2016), technological innovations that ensure the sustainability of food security are needed. Some of such technologies are heat and drought tolerant crop varieties and zero-till farming. Such technologies are sustainable intensification technologies causing an increase in yield without any (or minimal) environmental damage or conversion of non-agricultural land to agricultural land (Pretty and Bharucha, 2014). Other methods include extending knowledge and encouraging adoption of climate change adaptation techniques, rainwater harvesting structures, preventing crop raiding by wild animals and integrated pest management, providing better agricultural marketing facilities, etc. They play an important role on the supply side. On the demand side, sustainable healthy diets could play an important role. According to WHO (2019), sustainable healthy diets help fulfill all the dimensions of health. They put low environmental pressure, are safe, affordable and culturally acceptable. With twin goals of sustainable intensification and sustainable healthy diets, sustainable food security could be achieved.

Application and Limitations of SFSTI

The universally applicable variables are the source of the indicators utilized to construct SFSTI. Table 1 presents the relationship with sustainable food security generalized for the whole country. As a result, SFSTI would apply to each state's constituent districts. However, since SFAcI is primarily based on the trade-off explained by migration, the SFSTI would produce results that are clearly interpretable for the states where migration is a significant concern.

While the SFSTI captures key agricultural and economic trade-offs influencing food security in Uttarakhand, it is important to acknowledge that, unlike some regions of the Indian Himalayas (Sood & Dhyani, 2024), reliance on urban foraging appears limited within Uttarakhand's urban centers. This suggests a greater dependence on formal food supply chains and market access, underscoring the importance of factors captured by the SFSTI in ensuring food availability and affordability for urban populations.

Since sustainability trade-offs must be addressed using long-term data, a 52-year dataset has been employed for this study. We used a dataset of districts with historical boundaries in order to address the issue of long-term data availability. The dataset with revised boundaries could be used in future studies to improve the focus and applicability of the policy suggestions for the existing districts. Further, it would be more helpful to delineate the policy recommendations at the geographical level of plains and hills, as the agro-economic and ecological conditions differ with the change in geography.

Future research may also focus on the development of a similar index for the household level, incorporating a multi-index-based assessment. Multi-index-based assessment involves the use of several indices like household food insecurity access scale, household dietary diversity score and household food insecurity access prevalence (Borku et al., 2024). Multi-index-based assessment has an added advantage as it makes validation and comparison easier. In contrast, the index developed in the current study measures trade-offs associated with the sustainability of food security, which have not been assessed in the past. Therefore, the current study has a limitation of validation through the use of similar indices. Niti Aayog, for that matter, has developed an index to track the progress of states of India in achieving Sustainable Development Goals, which includes Sustainable Development Goal-2 of Zero Hunger (NITI Aayog, 2024). However, the index does not explicitly use a panel/time-series dataset, unlike the requirement of the index in the current study.

CONCLUSIONS AND RECOMMENDATIONS

The study aimed to analyze the sustainability of food security using the sustainable food security trade-off index and its components in different districts of Uttarakhand. Specific areas that require attention to improve the sustainability of food systems were identified for these districts. For instance, in Dehradun, the focus should be on ensuring sustainable food availability security, while in Tehri Garhwal, emphasis should be placed on sustainable food accessibility. In Uttarkashi, attention is needed to improve food utilization. By addressing these individual components and adopting sustainable intensification technologies and healthy diets, Uttarakhand can progress towards sustainable food security.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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