Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

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Crop Diversification and Nutrition Security: Extent, Linkage and Determinants

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ABSTRACT

Since the Green Revolution era, the cropping pattern in parts of northern India, which includes parts of Uttarakhand, has been dominated by paddy and wheat. Crop diversification is said to have a positive relationship with food and nutritional security. It is essential to consider where such dominant cropping patterns or crop diversification have led us in terms of food and nutritional security. This study examines the extent of district-level crop diversification in Uttarakhand using the Simpson index of diversification, as well as the extent of district-level nutritional security using the nutritional diversification index, for the period 1990–2019. Average values of the crop diversification index and nutritional diversification index for the periods 1990–99, 2000–09, and 2010–17 were calculated. It was found that crop specialization has occurred in the plain districts of Uttarakhand, namely Udham Singh Nagar and Haridwar, whereas in the remaining 11 hilly districts, crop diversification has largely prevailed. The results of nutritional diversification were mixed in hilly districts. Only Champawat and Dehradun clearly showed nutrition diversification and nutritional specialization, respectively. In the two plain districts, nutritional diversification was observed over the first two decades, after which nutritional specialization was observed. The development of bio-

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ARTICLE INFO
Received: 14 April 2025 | Revised: 13 June 2025 | Accepted: 16 June 2025 | Published Online: 11 July 2025
DOI: https://doi.org/10.36956/rwae.v6i3.2000

CITATION
Srivastava, S., Srivastava, S. K., 2025. Crop and nutritional diversification for sustainable food security: extent, linkage and determinants. Research on World Agricultural Economy. 6(3): 236–248. https://doi.org/10.36956/rwae.v6i3.2000

fortified varieties and ensuring access to safe and nutritious food for all people are key ways to achieve food and nutritional security through crop diversification.

Keywords: Crop Diversification; Nutrition Security; Food Security; Uttarakhand

1. Introduction

Agricultural diversification, which includes crop diversification, is a significant way to realize higher farm income, increased output growth, sustainability of natural resources, employment generation, and poverty alleviation. The experience from the Middle East, Southeast Asia and North Africa supports that policymakers and planners have been focusing on crop and agricultural diversification to promote the development of agriculture [1]. Many researchers support the notion that agricultural diversification is a valuable instrument that can be used to alleviate poverty, generate employment opportunities, increase farm income, and conserve natural resources [2–5].

Crop diversification is seen as one of the most important, cost-effective, ecologically feasible, and rational ways of decreasing uncertainties in agriculture, including those among smallholder farmers [6]. It also enhances resilience, is more stable agronomically, and ensures greater temporal and spatial biodiversity in farms [6,7]. The resilience is mainly due to the factors such as lower weed and insect pressures, decreased dependence on nitrogen fertilizers (resulting from the inclusion of leguminous crops), reduced erosion (mainly due to the use of cover crops), and enhanced yield per unit area and soil fertility [8]. Crop diversification can also improve resilience to climate [9] and lead to natural resource conservation.

According to Paroda [10], during the Green Revolution period, cereals, primarily paddy and wheat, were the major focus. It has been observed over the years that the food basket has been diversifying. However, there is yet a predominance of rice–wheat cropping systems, especially in Haryana, Punjab and Uttar Pradesh (UP); winter maize in Bihar with very high yield (> 7.0 tons/ha); groundnut in Gujarat; chickpea in south India (due to the development of short duration varieties); sugarcane in the north (owing to the mobilization of sugarcane by transfer of both disease and drought tolerance from Saccharum spontaneum); soybean in Madhya Pradesh and its adjoining states; and pigeon pea in north-western states like Punjab, Haryana, Gujarat and Rajasthan (due to early maturing varieties [approximately 120 days]). It is an important question to answer: where have such dominant cropping systems brought us in terms of food and nutritional security?

Crop diversification is a dynamic tool that can ensure food security in a sustainable manner [11]. A positive relationship exist between crop diversification and household food security status [12]. A crucial question here is what the relationship could be between crop diversification and food and nutritional security at the district level, and what the determinants of this relationship might be. Uttarakhand is a state that comprises of 13 districts, out of which 2 are plain districts, while 11 are wholly hilly or a mix of plains and hills. It is characterized by poor agricultural development, primarily due to inadequate irrigation facilities, small landholdings, a geography prone to soil erosion and landslides, and other problems that have limited agriculture's ability to generate a substantial income for the state's residents. In this backdrop, the aims to analyze the trends and the extent of crop and nutritional diversification at the district level in Uttarakhand, along with identifying the relationship between crop and nutritional diversification and their drivers. In this study, nutritional diversification index developed here has been considered indicative of nutritional security at macro level.

2. Materials and Methods

2.1. Study Area

Uttarakhand is located in Central Himalaya region, covering an area of 53,483 km^2 [13]. The region has varied climatic zones along the altitude gradient, ranging from sub-tropical in the lower altitudes of the southern area to alpine and arctic types in the high altitudes of the extreme northern area. Agriculture is the main occupation of the local people of Uttarakhand [14]. The net sown area in Uttarakhand is 647,788 hectares [13]. The land-holding size in the state of Uttarakhand can be categorised as marginal, as 74% of holdings are less than 1 ha, and 16% are small being between 1 and 2 ha [13]. The small and scattered land holdings, coupled with rugged terrain, pose challenges to the economic viability of traditional agriculture in present times. In Kumaun Hills, the average annual income of agriculture-based farm households is about Rs. 1.6 lakh. For labour income-based households, the average yearly income is Rs. 2.3 lakh, and for government service-based households, it is Rs. 6.2 lakh [15]. In the high hills, livelihood diversification is found to be the highest, followed by the mid hills and the low hills in the Kumaun region [16].

The mainland of Uttarakhand is primarily surrounded by mountains. The hilly region spans 46,035 sq. km (86.07% of Uttarakhand's total area). The plain area spans over 7,448 sq. km (13.93%) of Uttarakhand's geographical area [13]. There are 2 divisions in Uttarakhand: Garhwal and Kumaun. There are 7 districts in the Garhwal division, namely Chamoli, Rudraprayag, Tehri, Uttarkashi, Pauri, Dehradun, and Haridwar. There are 6 districts in the Kumaun division, namely Udham Singh Nagar, Nainital, Pithoragarh, Champawat, Almora, and Bageshwar. The cultural and socio-economic aspects of both these geographical areas are varied. There is 1 plain district (Udham Singh Nagar) in Kumaun and 1 plain district (Haridwar) in Garhwal. The rest of the districts are either hilly or a mix of hills and plains.

2.2. Data Sources and Methodology

The study is based on secondary data. It utilizes district-level panel data on area and production of various crops, annual rainfall, cropping intensity, and gross irrigated area data for Uttarakhand from 1990 to 2017. This dataset, compiled by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Tata-Cornell Institute (TCI), is known as the District Level Database for India (DLD-India) [17]. The study involves the estimation of crop diversification index and nutritional diversification index, as well as the identification of the relationship between these two indices and their determinants.

2.2.1. Crop Diversification Index

To assess crop diversification, the Simpson index of diversification was used as the Crop Diversification Index (CDI). The Simpson Index is based on the proportion of area under crops in a geographical region. It can be computed efficiently and highly interpretable. The CDI is given by the following Equation (1):

$$\mathrm{CDI} = 1 - \sum\nolimits_{i}^{n} P_i^2 \tag{1}$$

where P_i is the proportion of area under i^{th} crop in the gross cropped area. CDI ranges from 0 to 1. A value close to 1 indicates high diversification, and a value close to 0 indicates zero or no diversification. The CDI was assessed for both food crops and non-food crops in each district of Uttarakhand state, India, for the period 1990–91 to 2018–19. The food crops group included foodgrains, sugarcane, fruits, and vegetables, while the non-food crop group comprised oilseeds and fodder crops. The data was linearly interpolated to fill the data gaps.

2.2.2. Nutritional Diversification Index

To assess nutritional diversification, a Nutritional Diversification Index (NDI) was developed, which is indicative of the level of nutritional security ensured by major crops (foodgrains, oilseeds, and sugarcane) that are part of the dominant cropping patterns. Traditionally, before the Green Revolution, agriculture was more diversified and sustainable [18]. Over the years, the rice-wheat cropping system has become predominant in north India [10]. To measure the extent of nutritional security ensured by these new cropping systems, NDI was used. It measures the dispersion of nutrients obtained from the production of the major crops and explains whether output from these new cropping systems is biased towards a particular nutrient. The NDI has been developed on the lines of the Simpson index of diversification and is given by the following Equation (2):

$$\mathrm{NDI} = 1 - \sum_{i}^{n} p_i^2 \tag{2}$$

where p_i is the proportion of i^{th} nutrients (protein, fat, minerals, fibre, or carbohydrate) to the total grams of nutrients obtained through the production of different crops. The NDI ranges from 0 to 1. A value nearing 1 indicates high diversification of nutrients, and a value nearing 0 indicates specialization. To determine the quantity of individual nutrients, food composition tables provided by Gopalan et al.[19] were used. For the conversion of sugarcane into equivalent sugar, the average sugar recovery rate of India was used. To average out individual nutrient quantities for the category of 'minor pulses', the mean of each nutrient of minor pulses (horsegram, lentil, and pea) grown in Uttarakhand was used.

2.2.3. Relationship between NDI and CDI

By using different curve equations, the relationship between NDI (dependent variable) and CDI (independent variable) has been described. The following are the different models:

Linear function: In the linear model, all parameters are linear, i.e. homogenous of degree one. Mathematically expression of linear Equation (3) is

$$\mathrm{NDI}_{it} = \alpha + \beta \mathrm{CDI}_{it} \quad (3)$$

where α is a constant, and β is a parameter.

Logarithmic function: It shows a very rapid increase followed by a slower one. Following is the mathematical expression of the function in Equation (4):

$$\mathrm{NDI}_{it} = \alpha + \beta \log(\mathrm{CDI}_{it}) \quad (4)$$

where α is a constant, and β is a parameter.

Inverse function: This function shows a decreasing curve. The Equation (5) of the inverse function is as follows.

$$\mathrm{NDI}_{it} = \alpha + \beta/\mathrm{CDI}_{it} \quad (5)$$

where α is a constant, and β is a parameter.

Quadratic function: When there is a trough or a peak in the data, the quadratic function is useful. The Equation (6) of a quadratic function is as follows:

$$\mathrm{NDI}_{it} = \alpha + \beta \mathrm{CDI}_{it} + \gamma \mathrm{CDI}_{it}^2 \quad (6)$$

where α is a constant, and β and γ are parameters.

Cubic function: When there are two peaks or two troughs in the data, the cubic function is useful. Its Equation (7) is as follows:

$$\mathrm{NDI}_{it} = \alpha + \beta \mathrm{CDI}_{it} + \gamma \mathrm{CDI}_{it}^2 + \delta \mathrm{CDI}_{it}^3 \quad (7)$$

where α is a constant, and β, γ, and δ are parameters.

Compound function: When it is known that there is a rising curve or falling curve, the following Equation (8) is used:

$$\mathrm{NDI}_{it} = \alpha \beta^{\mathrm{CDI}_{it}} \quad (8)$$

where α is a constant, and β is a parameter.

S-curve: It is used when exponential relation is observed. The Equation (9) of S – curve is as follows:

$$\mathrm{NDI}_{it} = \mathrm{Exp}(\alpha + \beta/\mathrm{CDI}_{it}) \quad (9)$$

where α is a constant, and β is the parameter.

Growth function: It is used when there is a direct exponential relationship. The Equations (10) and (11) are as follows:

$$\mathrm{NDI}_{it} = \mathrm{Exp}(\alpha + \beta \mathrm{CDI}_{it}) \quad (10)$$

or

$$\ln(\mathrm{NDI}_{it}) = \alpha + \beta(\mathrm{CDI}_{it}) \quad (11)$$

where α is a constant, and β is the parameter.

Power function: It is the relationship observed when the dependent variable is directly proportional to some power of the independent variable [Equations (12) and (13)]:

$$\mathrm{NDI}_{it} = \alpha \mathrm{CDI}_{it}^{\beta} \quad (12)$$

or

$$\ln \mathrm{NDI}_{it} = \ln \alpha + \beta \ln(\mathrm{CDI}_{it}) \quad (13)$$

where α is a constant, and β is a parameter.

The strength of the above relationships is judged by the significance of the regression, high R^2 or adjusted R^2 and high F-ratio.

2.2.4. Panel Data Regression Model

To assess the determinants of crop diversification and nutrient diversification at the district level, the fixed effect model (FEM) and random effect model (REM) were used. The panel data set was balanced, i.e. the dataset had an equal number of observations for each individual (district). For the appropriate model selection between FEM and REM, the Hausman specification test was performed to check the appropriateness of the regression for panel data modelling. The sample size had 364 observations. The regression equation was modelled to find the association between CDI or NDI (dependent variable) and cropping intensity, gross irrigated area and annual rainfall (independent variables).

The FEM has constant slopes. However, the intercepts differ by the cross-sectional (districts) unit. For i number of classes, i–1 number of dummy variables are used to designate a particular district. It is flexible in accommodating heterogeneity (or individuality) among districts (units), as each district can have its intercept value. Thus, the intercept may vary by district, but it does not vary over time. Unlike FEM, in a random effect model (REM), it is assumed that the intercept is a random outcome variable. The random outcome is a function of a mean value in which a random error is added.

Fixed Effect Model

To account for the individuality of each district (cross-sectional unit), the intercept is varied by using a dummy variable for fixed effects. Fixed effect models for panel data (intercept or individual) can be given by the following Equation (14):

$$Y_{it} = \beta_{1i} + \beta_2 CI_{it} + \beta_3 RAIN_{it} + \beta_4 GIA_{it} + u_{it} \quad (14)$$

where i = 1, 2, 3,....,13 [cross section (districts)], t = 1,2,3,...........,30 [time period (years)], Y is CDI or NDI, CI =Cropping intensity, RAIN=Annual rainfall; GIA =Gross irrigated area, u =Stochastic error-term.

Random Effect Model

In the random effect (REM) model, the assumption is that the individual-specific coefficient β_{1i} is fixed for each time-invariant individual. It is also assumed that β_{1i} is a random variable with a mean value of β_1 (without i subscript here). It is expressed by the following Equation (15):

$$\beta_{1i} = \beta_1 + \varepsilon_i \quad (15)$$

where ε_i is a random error-term with mean '0' and variance '$\sigma^2_{\varepsilon_i}$'. Thus, random effect model for panel data can be expressed by the following Equation (16):

$$Y_{it} = \beta_1 + \beta_2 CI_{it} + \beta_3 RAIN_{it} + \beta_4 GIA_{it} + w_{it} \quad (16)$$

where, $w_{it} = \varepsilon_i + u_{it}$.

The composite error-term w_{it} has two components: ε_i, representing the cross-section or individual-specific error component, and u_{it}, representing the combined time series and cross-section error component.

3. Results

3.1. CDI and NDI

Table 1 presents the average CDI values for the periods 1990–99, 2000–09, and 2010–19. It was found that over the years, crop diversification has increased in the hilly districts of Chamoli, Almora, Champawat, Nainital, Dehradun, Pauri Garhwal, Pithoragarh, Tehri Garhwal, and Uttarkashi. In the plain districts of Udham Singh Nagar and Haridwar, there has been a trend towards crop specialization. In Rudraprayag, the average CDI increased over 2 decades, from 1990–99 and 2000–09, after whichit stagnated.

Table 1. Average Crop Diversification Index (CDI).

District	1990–99	2000–09	2010–19
Almora	0.629	0.714	0.740
Bageshwar	0.630	0.720	0.710
Chamoli	0.652	0.760	0.777
Champawat	0.778	0.783	0.803
Dehradun	0.805	0.818	0.822
Haridwar	0.777	0.731	0.708
Nainital	0.771	0.832	0.837
Pauri Garhwal	0.670	0.764	0.798
Pithoragarh	0.719	0.765	0.778
Rudraprayag	0.688	0.720	0.720
Tehri Garhwal	0.651	0.766	0.788
Udham Singh Nagar	0.720	0.686	0.632
Uttarkashi	0.714	0.790	0.814

Table 2 presents the average NDI values for the periods 1990–99, 2000–09, and 2010–19. In Almora, Bageshwar, and Uttarkashi, nutritional diversification showed slight specialization over the first 2 decades, after which the NDI increased. In Haridwar, NDI showed specialization over the first 2 decades, after which NDI increased. In Chamoli, Pauri Garhwal, Pithoragarh, and Uttarkashi, a specialization trend was observed

in the second decade, followed by diversification that was slightly more pronounced than in the first decade. Champawat clearly demonstrated diversification in nutritional diversity, whereas Dehradun showed specialization over the period. In Udham Singh Nagar district, there was slight diversification towards the second decade, after which nutritional diversification was slightly less than the first decade was observed. In Nainital and Rudraprayag, a notable increase in nutritional diversification was observed over the decades. In Tehri Garhwal, the average NDI was remained over the first 2 decades, after which it showed slight diversification.

The Gantt charts for CDI and NDI, plotted using Tableau, are shown in **Figure 1** for each district. The trends do not show extremely high escalations or downfall. The trends are showing only a slight rise or fall and are more or less stable over the years. In Haridwar and Udham Singh Nagar, which are plain districts, overall decreasing trends in NDI and CDI were observed, indicating specialization over the years. In contrast, in Pauri Garhwal, Nainital, Tehri Garhwal, Pithoragarh, and Uttarkashi, clear overall increasing trends were observed, indicating diversification.

Table 2. Average Nutritional Diversification Index (NDI).

District	1990–99	2000–09	2010–19
Almora	0.318	0.312	0.357
Bageshwar	0.316	0.312	0.356
Chamoli	0.314	0.311	0.357
Champawat	0.314	0.320	0.370
Dehradun	0.353	0.350	0.382
Haridwar	0.338	0.324	0.343
Nainital	0.324	0.325	0.363
Pauri Garhwal	0.323	0.318	0.365
Pithoragarh	0.325	0.321	0.369
Rudraprayag	0.306	0.310	0.352
Tehri Garhwal	0.325	0.325	0.371
Udham Singh Nagar	0.318	0.320	0.279
Uttarkashi	0.329	0.326	0.370

The ranks of NDI and CDI are shown in **Figure 2**. The nutritional diversification increased as crops diversified into millets. The NDI index indicated greater specialization as the cropping system focused on rice and wheat.

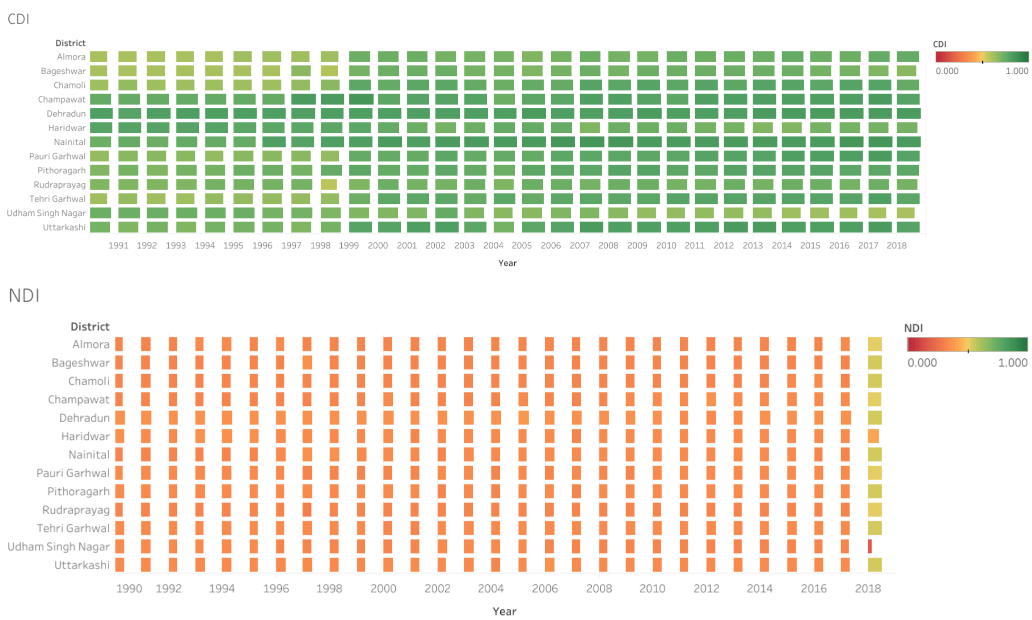

Figure 1. Gantt Chart Showing CDI and NDI.

3.2. Relationship between NDI and CDI

Models were fitted to find the relationship between NDI and CDI using Statistical Package for the Social Sciences (SPSS). **Table 3** presents the results of different fitted models that describe the relationship between NDI (dependent variable) and CDI (independent variable). It can be observed from the table that all the proposed models were found to be significant. However, the best-fitting model is the S-model, as it has the highest R^2, followed by the highest F-value. The best fitting S-relationship is shown in **Figure 3.**

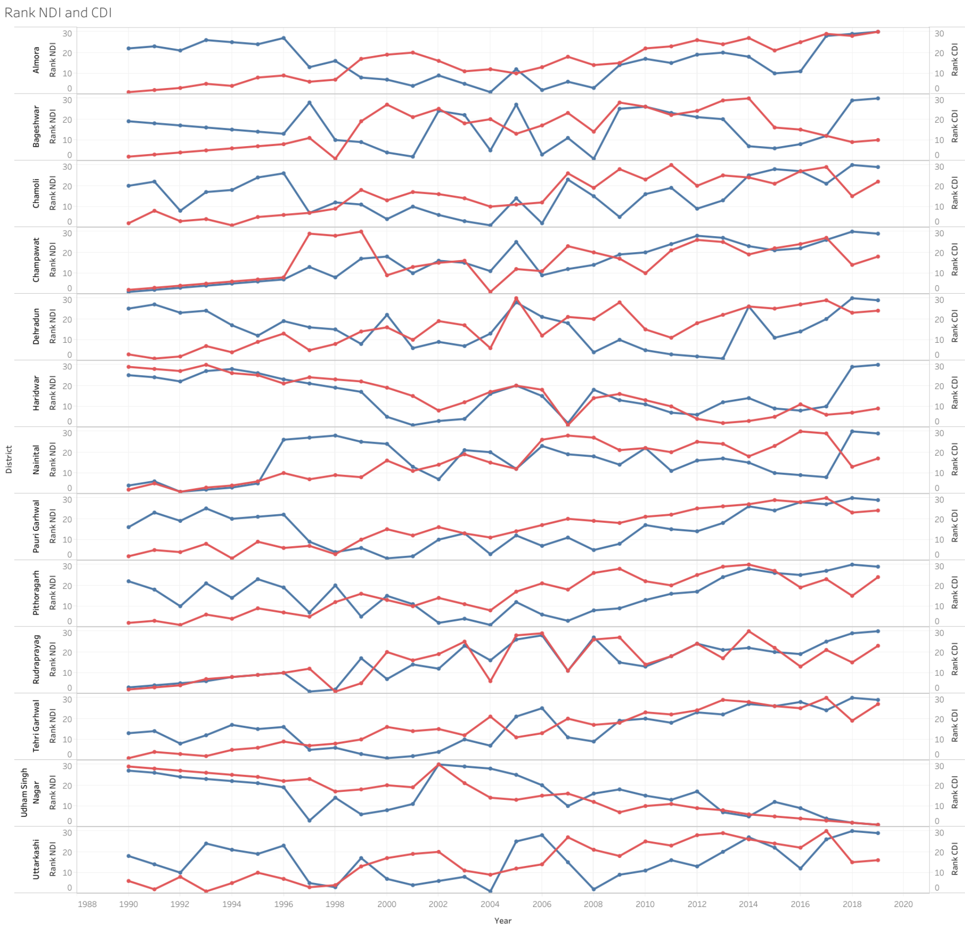

Figure 2. Ranks of NDI and CDI.

Note: CDI rank is shown in red. NDI rank is shown in blue.

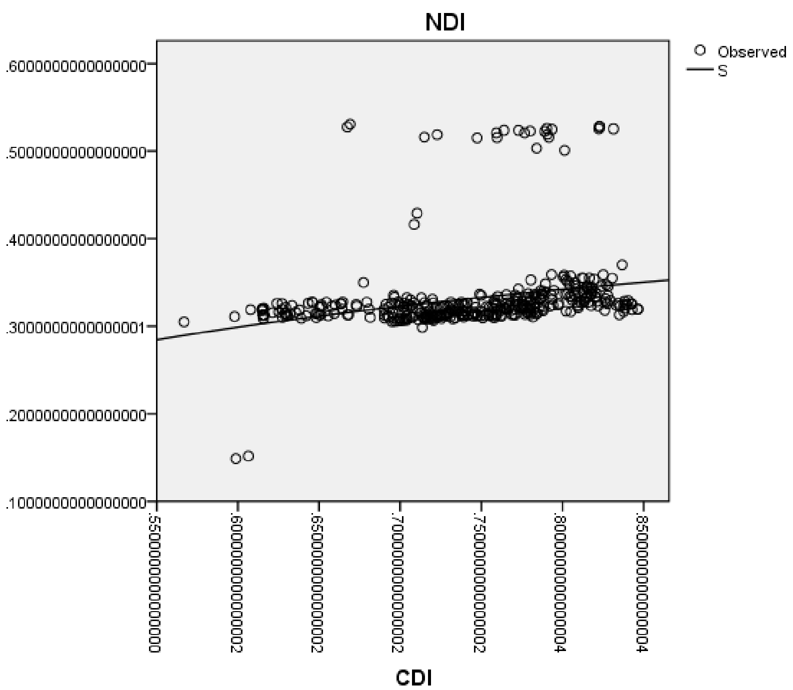

Figure 3. NDI versus CDI.

Table 3. Relationship Between NDI and CDI.

Equation	R^2	F-Value	p-Value	α	β	Γ	Δ
Linear	0.064	26.716	0.000	0.204	0.182		
Logarithmic	0.065	26.777	0.000	0.148	0.378	–	
Inverse	0.064	26.710	0.000	-0.106	0.477		
Quadratic	0.065	13.353	0.000	0.112	0.399	-0.134	
Cubic	0.065	13.354	0.000	0.134	0.304	5.328	-0.063
Compound	0.085	35.874	0.000	0.209	1.854		
Power	0.086	36.295	0.000	0.378	0.449		
S	0.086	36.572	0.000	-0.669	-0.323	–	
Growth	0.085	35.874	0.000	-1.566	0.617		

3.3. Determinants of NDI

The identification of the determinants of nutritional diversification at the district level was done by employing panel data regression models, viz. fixed effect and random effect models (REM). To select the appropriate model, the Hausman specification test was performed. The Hausman specification test results were obtained using h2o.ai and are presented in **Table 4**. The Hausman test with the a p-value < 0.05 led to the acceptance of the null hypothesis and the conclusion that the Fixed Effects Model is appropriate. Therefore, FEM was applied to estimate the parameters of NDI over the period 1990–2019.

Table 4. Hausman Specification Test Results for Regression for Nutritional Diversification Index (NDI).

Statistic	Value			
Hausman Statistic	72.82			
P-value	1.11e-15			
Conclusion	Alternate hypothesis is accepted. Fixed Effects Model is preferred.			
Variable	**Fixed Effects Model**		**Random Effects Model**	
	Coefficient	**P-value**	**Coefficient**	**P-value**
Annual Rainfall	0.000010	0.1719	0.000028	0.0001*
Gross Irrigated Area	-0.000140	0.1782	-0.000157	0.0548
Cropping Intensity		-0.001199	0.001853	0.0000*
*Statistically significant at p < 0.05				

The results indicate that cropping intensity has a statistically significant and negative impact on nutritional diversification throughout the study period. The effect of annual rainfall and gross irrigated area on the nutritional diversification index was not found to be statistically significant.

3.4. Determinants of CDI

The determinants of crop diversification at the district level were analyzed using FEM and REM. To obtain the best model, the Hausman specification test was used. The results of the Hausman specification test, obtained by employing h2o.ai, are presented in **Table 5**. The Hausman test showed that the p-value = 1.00 failed to reject the null hypothesis. Hence, the REM was found to be suitable for estimating the parameters of CDI over the period 1990–2017.

The results show that gross irrigated area and cropping intensity have a negative and statistically significant impact on crop diversification throughout the study period. The effect of annual rainfall on the nutritional diversification index was not statistically significant.

Table 5. Hausman Specification Test Results for the Regression of the Crop Diversification Index (CDI).

Statistic	Value
Hausman Statistic	-86.55
P-value	1.0000
Conclusion	Fail to reject the null hypothesis. Random effects model is preferred.

Table 5. *Cont.*

Variable	Fixed Effects Model		Random Effects Model	
	Coefficient	P-value	Coefficient	P-value
Annual Rainfall	-0.00000784	0.4565	0.00008068	0.0009*
Gross Irrigated Area	-0.00031972	0.0000*	0.00009252	0.5335
Cropping Intensity	-0.00422095	0.0000*	-0.00025944	0.8460

*Statistically significant at p < 0.05

4. Discussion

This study examines the district-level Crop Diversification Index (CDI) and Nutritional Diversification Index (NDI) in Uttarakhand, their linkage, and determinants. The NDI is indicative of nutritional security ensured at the macro level through dominant cropping systems.

Average NDI values were not found to fluctuate significantly, varying between 0.3 and 0.4 only. It was found through the average values of CDI that slight crop specialization is occuring in the plain districts of Uttarakhand. Both of the plain districts have industrial hubs facilitated by the State Infrastructure and Industrial Development Corporation of Uttarakhand Ltd. (SIIDCUL). Commodities such as peas, paddy seeds, and sugarcane are being supplied to companies or mills established in this area. Since marketing facilities are available for these commodities, farmers have shifted to cultivating these crops. NDI demonstrated specialization and progressed along CDI in these districts. However, the overall relationship between NDI and CDI was found to be nearly S-shaped, indicating that NDI first decreased with an increase in CDI as diversification was increasing, but with further diversification, NDI increased. This suggests that in Uttarakhand, slight nutritional specialization occurred until a threshold value of CDI was reached, after which nutritional security was enhanced with an increase in crop diversification. This implies that until the attainment of the threshold level, crop diversification was occurring in crops rich in a particular nutrient. Anuja et al.[20] have reported an inverse relationship between crop diversification and undernutrition in India. This confirms that nutrition security improves as long as there is crop diversification in the nutrient-rich crops. The nutrient-rich crops, for instance, could be finger millet, vis-à-vis rice and wheat, owing to the fact that finger millet has a higher proportion of minerals.

The crop diversification status is an indicator of adaptation as a response to climate change, and market access facilities and specialized labour requirements that may not be fulfilled to diversify the current cropping system. For instance, in response to low rainfall caused by climate change, farmers, especially small marginal farmer, who are mostly dependent on rainfed farming, may opt for cultivating other kharif crops that are not water-guzzling. In particular, the plain district of Udham Singh Nagar had witnessed an increase in the cultivation of the water-guzzling summer paddy crop. While large farmers can avail themselves of the facility of tubewells, the smallholder farmers might find the electricity expenses unaffordable. Owing to this reason, small and marginal farmers might switch to other crops or leave part of their land fallow. On the other hand, resource-rich farmers usually adapt to climate change by bringing more area under irrigation and planting more crops, thereby improving cropping intensity and crop diversification. However, in the current study, gross irrigated area and cropping intensity are found to have a negative relation with CDI, which could be indicative of poor climate change adaptation, crop failure, low yields, low preparedness to cope with climate change, low market access and scarcity of skilled labour. As CDI is negatively related to cropping intensity, the same relationship is reflected in NDI as well, given that CDI and NDI are correlated.

Average values indicate that, most hilly districts, crop and nutritional diversification were observed. However, there is still considerable scope for diversification, as only 4 percent of the total reported area the of state is under horticulture. Regarding the status of agricultural technology, none of the hill districts have an average consumption of chemical fertilizer above 10 kilograms per hectare. Around 74 percent cultivators in this region are marginal farmers, constituting about 36 percent of the total arable land. The average yield of different traditional crops grown in this region is 11.0 quintals per hectare for barley, 10.25 quintals per hectare for wheat, 18.16 quintals per hectare for the mixed crop of finger millet and horse gram, 26.18 quintals per hectare for the mixed crop of paddy, barnyard millet and foxtail millet; total food grains to be at 18.84 quintals per hectare and 18.46 quintals per hectare amaranth [21]. Pandey et al. [22] mention the introduction of medicinal and aromatic crops with horticultural crops in the cropping system of Uttarakhand as the climate and topography of Uttarakhand are suitable for these crops. Another possible way to diversify the cropping system in the state is through the promotion of the cultivation of traditional organic crops like amaranth and buckwheat. The agro-climatic conditions of Uttarakhand are best suited for floriculture, but the poor transportation linkage is the foremost hurdle as it requires advanced transport facilities and prompt delivery [21].

Market-led extension and agronomic extension services should be provided while ensuring an optimal ratio of extension workers per hundred farmers. Given that women in Uttarakhand, perform extensive agricultural functions, it is essential to ensure that a sufficient number of women extension functionaries are employed in the extension system due to the cultural and social reasons. To achieve crop diversification, specialized labour would be required who would be able to perform operations not only on rice and wheat crops but also on several other crops, such as finger millet, maize, and legumes. Specialized training should be organized to educate farm labourers in the cultivation of different crops using modern technologies. With the availability of skilled farm labour, the wage market might also reach a balance, thereby making the production of diversified crops more profitable. In rural areas, custom hiring centres have been established to offer farm machinery on a rental basis. In the same fashion, hiring platforms to match available skilled labour with the recruiting farm owner can be developed to drive nutritional and crop diversification programs in the future.

On the other hand, market-led extension enables farmers to identify market opportunities and achieve higher profits in a competitive environment. Extension functionaries work closely with farmers and other market actors, such as input processors and suppliers. The market-led extension ensures that farmers have access to the market and inputs.

Gross irrigated area and cropping intensity were found to be the main determinants of CDI and NDI, and both showed a negative relationship with CDI and NDI. This is in contrast with Joshi et al. [23] and Kumar and Gupta [24], who found that cropping intensity and annual rainfall are the major determinants of CDI in India and are positively related to CDI.

Ensuring access to nutritious food along with nutritional diversification is essential. The development, adoption, and consumption of biofortified varieties of different crops (e.g., golden rice), along with crop diversification, are the important ways of ensuring nutritional security at the macro level. Specifically, purple, blue, and black wheat are rich in anthocyanins. While the common white wheat contains 5 ppm of anthocyanins per 100 g, the purple, blue, and black wheat contains 40, 80, and 140 ppm of anthocyanins, respectively [25]. Biofortified varieties of other foodgrain crops are also available for commercial cultivation. Traditional maize, for instance, contains a low amount of lysine and tryptophan protein. Several maize hybrids rich in provitamin A or rich in lysine, tryptophan, and provitamin A have been released for commercial cultivation. Other instances include zinc and iron-rich biofortified varieties of pearl millet [26]. Millets are nutritionally superior to rice and wheat, as they contain a high amount of dietary fibre, protein, vitamins, and minerals [27]. There lies a high potential for agronomic biofortification of finger millet [28].

It is estimated that over half of the world's population suffers from micronutrient malnutrition, which is one of the biggest threats to humanity. Historically, modern plant breeding has focused more on achieving high agronomic yields than nutritional quality, and other attempts to address the issue have mostly involved pharmacological supplements or industrial fortification. Women and preschool-aged children are particularly susceptible to micronutrient malnutrition, also known as "hidden hunger," which is mostly brought on by inadequate dietary intake of micronutrients, particularly zinc and iron. Malnutrition, also known as hidden hunger, can be prevented through biofortification, a process that enhances the bioavailable concentrations of critical elements in edible parts of agricultural plants via genetic selection or agronomic interventions [29].

Biofortification is of specific importance to the state of Uttarakhand as it has low levels of food and nutrition security, as demonstrated by various food insecurity indicators. For the period 2019–21, out of the thirteen districts of Uttarakhand, 5 districts demonstrate public health concern on the indicator of a number of anaemic pregnant women, 7 districts on the indicator of a number of underweight children (< 5 years), 11 districts on a number of underweight women, 12 districts on a number of anaemic children (< 5 years) and 13 on a number of stunted children (< 5 years) [30].

Besides this, it is equally important to ensure the sustainability of nutritional security by practicing climate-resilient agriculture and growing region-specific crops that can be grown sustainably. Th cultivation of millets, which are climate-resilient crops, should be encouraged by incentivising farmers through ecosystem services [31]. Improved farm practices such as integrated nutrient management and intercropping with legumes can be used to generate economic value by offering ecosystem services [32]. This will incentivise farmers to diversify into various nutrient-rich and climate-resilient crops that have the potential to ensure nutritional security through nutritional diversification.

Thus, on the production side, the selection of biofortified varieties, diversification into nutrient-rich and climate-resilient crops, and agronomic biofortification should be incentivised. Additionally, agronomic extension services should be provided to farmers. On the other hand, market access and market-led extension services, as well as monitoring for ecosystem services, should be provided. These initiatives would help in ensuring food and nutritional security.

This research is based on district-level data. Future research could utilise farm-household-level data on crop diversification and farmers' diets to investigate the relationship between crop diversification and food and nutritional security.

5. Conclusion

This study examined the extent of district-level crop diversification and nutritional diversification in Uttarakhand over the period 1990–2019, their relationship, and identified their determinants. Crop diversification was examined using the Simpson index of diversification, whereas the nutritional diversification index was developed on the lines of the Simpson index. It was found that crop specialization has been prevalent in plain districts, whereas in hilly districts, crop diversification has largely been the norm over the years. The results of nutritional diversification have been mixed. The relationship between nutritional diversification index and crop diversification index is S-shaped, which implies that nutrition security improves as long as there is crop diversification in the nutrient-rich crops. The statistically significant determinant of both the crop diversification index and nutritional diversification index is cropping intensity, showing a negative relation, which is indicative of poor climate change adaptation, crop failure, low crop yields, and low preparedness to cope with climate change: poor market access and paucity of skilled labour required to cultivate different types of crops.

In the districts of Uttarakhand, especially in the plain districts where crop specialization is increasing, marketing and extension facilities should be provided for crops other than paddy-wheat dominant cropping patterns, including other-crops. Ensuring food and nutritional security through crop diversification requires actions that include the development of bio-fortified varieties, ensuring access of all people to safe and nutritious food, boosting eco-friendly and region-specific production, shifting to consumption patterns that are sustainable, advancing equitable livelihoods and building resilience that combats shocks, vulnerabilities and stress. To achieve nutritional diversification, cropping systems should include biofortified crops, such as purple, blue, and black wheat, golden rice, and biofortified maize. Besides genetic biofortification, agronomic biofortification should also be encouraged, especially in the case of millets. Additionally, agronomic and market-led extension services should be provided.

Author Contributions

Conceptualization, S.S. and S.K.S.; methodology, S.S..; software, S.S..; validation, S.S. and S.K.S.; formal analysis, S.S.; investigation, S.S. and S.K.S.; writing—original draft preparation, S.S.; writing—review and editing, S.K.S.; visualization, S.S.; supervision, S.K.S. All authors have read and agreed to the published version of the manuscript.

Funding

The work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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