PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.8856

eISSN 2348-1900

RESEARCH ARTICLE

Diversification towards horticulture crops: District level evidence from Indian state of Karnataka - A panel regression approach

Radhika C[1,2*], Rajib Sutradhar[3], Mahesh E[1], Udaya Bhaskar Kethineni[4] & Jagdish Prasad[5]

[1]Department of Economics, Christ (Deemed to be) University, Bengaluru 560 029, Karnataka, India
[2]ICAR-National Bureau of Soil Survey (NBSS) and Land Use Planning (LUP), Regional Centre, Bengaluru 560 024, Karnataka, India
[3]Department of Economics, North-Eastern Hill University, Shillong 793 022, Meghalaya, India
[4]ICAR-National Institute of Seed Science and Technology (NISST), Regional Station, Bengaluru 560 065, Karnataka, India
[5]ICAR-National Bureau of Soil Survey (NBSS) and Land Use Planning (LUP), Nagpur 440 033, Maharashtra, India

*Correspondence email - radhika.kerala@gmail.com; radhika.c@icar.org.in

Received: 13 April 2025; Accepted: 16 June 2025; Available online: Version 1.0: 01 August 2025

Cite this article: Radhika C, Rajib S, Mahesh E, Udaya BK, Jagdish P. Diversification towards horticulture crops: District level evidence from Indian state of Karnataka - A panel regression approach. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.8856

Abstract

A growing strand of literature has highlighted a positive association between diversification towards high-value crops and poverty reduction in developing countries, largely drawing on household-level data. However, many socio-economic and biophysical factors operate at the meso (district) level, and their role in diversification towards high-value crops is not well understood. Against this backdrop, the present paper examines the case of the Indian state of Karnataka by drawing upon the panel data from 2001 to 2021 to study the determinants of diversification towards horticulture crops and their sub-sector at the district level. The results of a fixed-effects panel regression model show that increasing the share of horticulture does not necessarily promote diversification. The finding further revealed that factors driving the increasing share of horticulture crops vary in importance across different sub-sectors. Government and donor agencies would do well to note that a one-size-fit-all approach does not work form promoting diversification. It is imperative to develop tailored strategies that address the specific needs and conditions of diverse regions to effectively promote sustainable land-use practices. The study's findings reveals that demand-side factors like gross GDP (gross domestic product) per capita of the district and the degree of urbanization affect horticulture diversification positively. Furthermore, the study provides crucial insights into the impact of increasing population pressure, which is largely associated with rapid expansion of non–agricultural land. This trend negatively affects the availability of land allocated to horticulture and its sub-categories at the district level.

Keywords: crop diversification; determinants of land use change; fixed effects panel regression; high-value crops

Introduction

Approximately, two-third of the world's 680 million poor live in rural areas of developing countries, with smallholders account for the majority (1). A declining natural resource base, food and nutritional insecurity and climate change all contribute towards the persistence of poverty among the smallholders in the world. Diversification away from cereals and in favour of high-value crops namely, fruits, vegetables, livestock and fisheries, has been suggested as a way forward to enhance smallholders' income from farming (2). A burgeoning strand of literature on the food value chain over the past two and half decades has focussed on the challenges and opportunities of smallholder's participation in the food value chain (3, 4). Donor agencies and rural development programme have increasingly focused on building capacities among resource poor smallholders to make them part of export driven high value chain. However, most of these literatures have focused on adoption and expansion of high value crops by using household-level data, often overlooking the role of meso-level factors that may influence inclusion or exclusion.

Increasingly, the food value chain has been led by organized firm such as supermarket chains or export firm (3). These firms, acting as lead actors, make selection at several levels, starting with geography. Within a given geography, the actor selects farmers, with typically those who are better-endowed, who then figure in the supplier list (5). In other words, farmers with the same level of resource endowment may get excluded simply due to their geographic location. The success or failure of policies or government programmes is often context-specific and goes beyond individuals, influenced chiefly by institutional or social factors in a region. Many policy interventions for diversification in general and high-value crops in particular, occur at meso level. Against this backdrop, the present paper aims to explore drivers of diversification at the meso level. Drawing upon panel evidence of Indian state of Karnataka, the present study aims to document the meso level determinants of drivers of diversification towards horticulture and its various sub-sectors.

Indian context

In India, agriculture holds a significant position, employing more than 45 % of the country's workforce, with its share in GDP accounting for almost 20 % (2020-21) and the crop sector still being the major contributor to total gross value added (GVA) (6). However, Indian agriculture is at the crossroad, with records of high agricultural production and dipping fortunes of farmers, many of whom struggle to make ends meet. Around two-thirds of India's population is in rural areas, and a large proportion of this population lives in poverty (7). Evidence from the farmer situational assessment survey conducted by NSSO (National Sample Survey Organisation, Government of India (GoI)) shows that average monthly income and expenses (including both paid out and imputed costs) for crop production during the agricultural year July 2018-June 2019 were Rs. 8337 and Rs. 3739, respectively (8). The average size of operational holdings has declined to 1.08 ha in 2015-16, compared to 1.15 ha in 2010-11. Smallholder and marginal farmers, those with less than two hectares of land account for 86.2 % of all farmers (close to 126 million), yet they own just 47.3 % of the arable land (9). The co-existence of farmers' distress with record-breaking production figures typifies the current state of Indian agriculture. Farmer suicides due to indebtedness, frequently make headlines (10). In 2022, 11290 suicide cases were reported across India, according to the latest National Crime Records Bureau (NCRB) data released in December 2023 (11).

Over the past decade, diversification away from cereal production has been suggested as a pathway out of poverty and push farmers towards higher net income from farming (2, 12-14). The inter-ministerial committee set up by the GoI identified diversification towards high-value crops, including horticulture, as one of the key strategies to achieve the goal of "Doubling of Farmers Income (DFI) by 2022" (15). Recent literature has shown that diversification towards high-value crops positively affects poverty reduction as smallholders, better endowed with family labour, are more likely to benefit from such diversification (12). The diversification towards horticultural crops is both capital and labour-intensive, providing more opportunities for income and employment generation (16).

In 2020-21, India's horticultural production reached 331 million tons from a 27.59 million ha, surpassing food grain production of 308.65 million tonnes from 129.34 million ha (17). A study from eastern India reports that growing high-value crops is associated with a 4-5 % reduction in the probability of being poor (14). Horticultural crops are estimated to generate as much as seven times more income per unit of land than cereals in India (2). Additionally, the study further shows that gross returns on small farms are 75 % higher for fruits, 36 % higher for spices and 12 % higher for vegetables (18).

However, studies conducted at the meso level (such as district or sub-district level) are conspicuous by their absence, which is surprising given that many policy interventions for diversification in general and high-value crops, in particular, occur at the district or sub-district level. The idea that the district is the unit through which public policy intervention happens in India has an old history dating back to the 'Green Revolution', which identified regions endowed with better irrigation facilities in northern and southern India for experimenting with green revolution technology (19). More recently, the 'One District, One Crop' policy also serves as another example of intervention at the district level (15).

Our choice of Karnataka is driven by fact that the state is a front-runner in driving diversification towards high-value crops (Table 1). The state's rich agro-climatic variation (Table 2) and wide range of soils and climates support multiple cropping systems and offer tremendous potential for varied land-use options. Karnataka has been tagged as one of the proactive reformers in agricultural marketing, facilitating the participation of private players in the high-value crop value chain (20). In the backdrop of the above discussion, the present article attempts to explore the drivers of diversification using the district level panel data from the state of Karnataka over two decades in the context of decreasing cropland area per capita from 2000 to 2019, attributed to population growth outpacing cropland expansion globally (21).

Materials and Methods

Data

The study used district administrative level data in the analysis acknowledging contextual effects of higher geographical levels that is reportedly influence the geographical pattern of agricultural diversification towards high-value crops significantly.

In this study, secondary data from 27 districts of Karnataka for five time periods (2001-02, 2006-07, 2011-12, 2016-17 and 2020-21) were used. The data collected from the published reports of the Directorate of Agricultural Economics and Statistics, Government of Karnataka (GoK), as well as from reports on climatic data, demographic data, agricultural census data, public works department reports and credit data. The database covers climatic and socio-economic factors that are crucial in determining agricultural land use outcomes (9, 17, 22-29) (Table 3). It covers a range of variables, including geographical area, non-agricultural land usage, total cropped area, irrigated area, horticulture crop area and the distribution of land holdings across different size categories at the district level. Additionally, data were collected on population density, urban population figures, per capita income levels and the presence of credit institutions.

Study area

The study was conducted in Karnataka, a state situated in the southwestern region of India, covering an area of 191,791 km^2, with a population of approximately 61.1 million, with 60.6 % residing in rural areas across 30 districts (6). The choice was done considering the state's diverse topography and climate which facilitates the cultivation of over 200 crop varieties, including cereals, pulses, vegetables, fruits and plantation crops (30). Besides, Karnataka has seen an increase in its net sown area, rising from 54.65 % to 60.12 % between 2001-02 to 2020-21, (9) accompanied by a significant rise in the gross irrigated area by 3.3 million hectares in 2001-02 to 6 million

Table 1. Category-wise area and production share of horticulture crops in Karnataka 2020-21

Crop category	Share of area (%)	Share of production (%)
Fruits	16.4	33.9
Vegetables	19.88	45.07
Spice crops	12.67	4.5
Plantation crops	49.41	15.1
Commercial flowers	1.45	1.35
Medicinal and aromatic plants	0.08	0.07

Source: Department of Horticulture, GoK, 2023 (9)

Table 2. Districts classified under different Agro Climatic Zones (ACZ) in Karnataka

Districts	Agro Climatic Zone (ACZ)	ACZ Code
Bidar	Northeastern transition zone	1
Gulbarga, Raichur	Northeastern dry zone	2
Bagalkote, Bijapur, Gadag, Belgaum, Bellary, Koppal	Northern dry zone	3
Chitradurga, Tumkur, Davanagere	Central dry zone	4
Bangalore Rural, Bangalore Urban, Kolar	Southeastern dry zone	5
Chamarajanagar, Kodagu, Mysore, Mandya	Southern dry zone	6
Hassan, Shimoga	Southern transition zone	7
Dharwad, Haveri	Northern transition zone	8
Uttara Kannada, Chikmagalur, Kodagu	Hilly zone	9
Dakshina Kannada, Udupi	Coastal zone	10

Source: GoK, 2023 (9)

Table 3. Sources of secondary data used in the study

Data	Publisher	Website	Reference
Crop production and quinquennial agricultural census data	Directorate of Economics and Statistics, Government of Karnataka; Directorate of Economics and Statistics, Government of India	Reports - Directorate of Economics and Statistics (karnataka.gov.in) Karnataka Agri Portal http://www.agricoop.nic.in/ http://desagri.gov.in/	(9)
Land use statistics	Department of Agriculture and Co-operation Network, Government of India	Area Production Statistics (dac.gov.in)	(17)
Rainfall and temperature	Indian Meteorological Department (IMD), Pune; Karnataka State Natural Disaster Monitoring Centre, Bangalore	IMD - Data Supply Portal (imdpune.gov.in); Climate data from Karnataka State Natural Disaster Monitoring Centre (KSNDMC) and Karnataka State Disaster Management Authority (KSDMA)	(24)
Decadal population census reports	Office of the Registrar General and Census Commissioner, India	Census of India : Census India Library	(25)
Road density	Public Works, Ports & Inland Water Transport Department (PWP & IWTD), Government of Karnataka; Statistical Unit, Office of the Chief Engineer, Communication and Buildings (Bangalore)	Home - Public Works Department (karnataka.gov.in)	(26)
Credit institutions	State Level Banker's Committee, Karnataka	SLBC Karnataka https://slbckarnataka.com/	(27)
Area under horticulture	Department of Horticulture, Government of Karnataka	Home - Department of Horticulture (karnataka.gov.in)	(28)
District level data	Maps	K-GIS (karnataka.gov.in) https://ksrsac.karnataka.gov.in/	(29)

hectares in 2020-21. These changes reflect a marked shift towards high-value crops, such as vegetables and fruits (24). Based on the above insights, Karnataka was purposively selected for this study due to notable trends in land use changes over recent decades (31, 32). Fig. 1 and 2 illustrate Karnataka's district map and the land use and land cover map, respectively.

Choice of explanatory variables

To comprehensively understand the drivers of diversification towards high-value agriculture, the present study incorporated socio-economic variables (population density, rural income, share of urban population and share of small and marginal farmers), neighbourhood variables (land shares in total land) and physical variables (average annual rainfall and average annual temperature) in the analysis. Use of panel data and multifactorial approach provides a nuanced understanding of the determinants influencing land use decisions in horticultural agriculture.

Both demand and supply-side factors associated with the economy's structural transformation were included in the analysis. On the demand side, variables such as income per capita and urbanization were included, given their influence on land use outcomes in agriculture. Notably, income per capita was included in the model based on that higher income levels have been reportedly linked to diversification towards high-value crops, although some studies reported a negative impact on diversification towards vegetables and spices (30). Similarly, the urbanization variable was included, considering the reported negative impact on fruit diversification while positively impacting vegetable and spice crop groups (32). The study area encompasses regions with varying population densities. Therefore, demographic factors, including population density, were included into the model due to their positive association with the share of area under horticulture crops in total arable land and their association (33).

Supply-side factors such as access to credit was evaluated for their significance in influencing crop allocation. Access to credit was considered crucial for capital-intensive fruit cultivation, which is reportedly less critical for vegetable production, which is more labour – intensive in nature. Variable on credit access was considered based on their previously reported significance in agricultural studies (23). Land size was included as one of the important supply side factors in the model. The study differentiated between smallholders and large farmers based on land size and labour endowment. Smallholders, typically endowed with family labour, often favour labour-intensive crops like vegetables and spices and large farmers with less family labour may prefer fruit crops due to their capital-intensive nature and longer gestation periods. This classification was based on established patterns observed in agricultural production systems as per the existing literature (12, 30, 34, 35).

Infrastructure factor such as access to transportation, was included in the model for their role in reducing marketing risks and transaction costs, especially for perishable commodities like fruits and vegetables and based on their reported positive impact on diversification towards horticultural crops (30, 34). Biophysical factors, such as rainfall, were included in the study to assess their influence on land use choices in agriculture due to the reported positive influence of rainfall on the area under horticulture crops, in contrast to the negative effect reported in some other studies (30, 36).

Estimation method

The panel data regression model with fixed effects (allows district-specific intercepts) was applied to understand the determinants of land use in horticulture using 27 districts data of five time periods and eleven independent variables with the dependent variable. The proportion of area under horticulture crops in the total gross cropped area (directly measures the land use outcome of horticulture in total agriculture) as a dependent variable. The five time periods used were the five rounds of the agricultural census data for the years 2001-02, 2006-07, 2011-12, 2016-17 and 2020-21 and compiled the data for different dependent and independent variables. It is assumed that disturbances in panel data models are cross-sectionally independent for short panels with a larger cross-sectional dimension (N) than for the time dimension (T) (37). One of the assumptions of the fixed-effects model is that the unobservable entity (district) effects are correlated with the observed independent variables, such as covariance (Xi, α_i) is a non-zero value. Where Xi is a regression variable and has unobservable individual effects and α_i is unobservable entity effects.

Specification of the regression model with crop diversification index (SID: Simpson Index of Diversification) as dependent variable

Simpson's index of crop diversification: Various methods are available to analyse the crop concentration or diversification of crops or activities over time and space. Each method has limitations and strengths (38). In assessing the extent of crop diversification in this analysis, Simpson's index of crop diversification was employed, which collectively examines the nature of crop diversification across all crops (13). The crop categories used in the generation of SID are cereals, pulses, oilseeds, horticulture crops and commercial crops, which are the major crop categories used by Directorate of Economics and Statistics (GoI) for their classification of agricultural crops in India (9). Commercial crops include sugarcane, cotton and tobacco. Further, the following equation to assess the determinants of diversification at the district level was estimated.

$$SID_{it} = X_{k.it}\beta_k + \delta_t + v_i + \epsilon_{it} \quad \text{(Eqn. 1)}$$

Where,

Yit = response variable such as index of diversification.

Xit= regressor variables for i=1,2,3.... n and t=1,2,3...t βk= coefficients for the respective k regression variables (both independent variables) in Xi.

$$SID = 1 - \sum P_i^2$$

Where,

Pi is the proportion of the ith crop/crop sector in the gross cropped area.

SID ranges between 0 and 1, wherein the value closer to 1 indicates high diversification and the value closer to 0 indicates no diversification or mono-cropping.

Fig. 1. District Map of Karnataka.

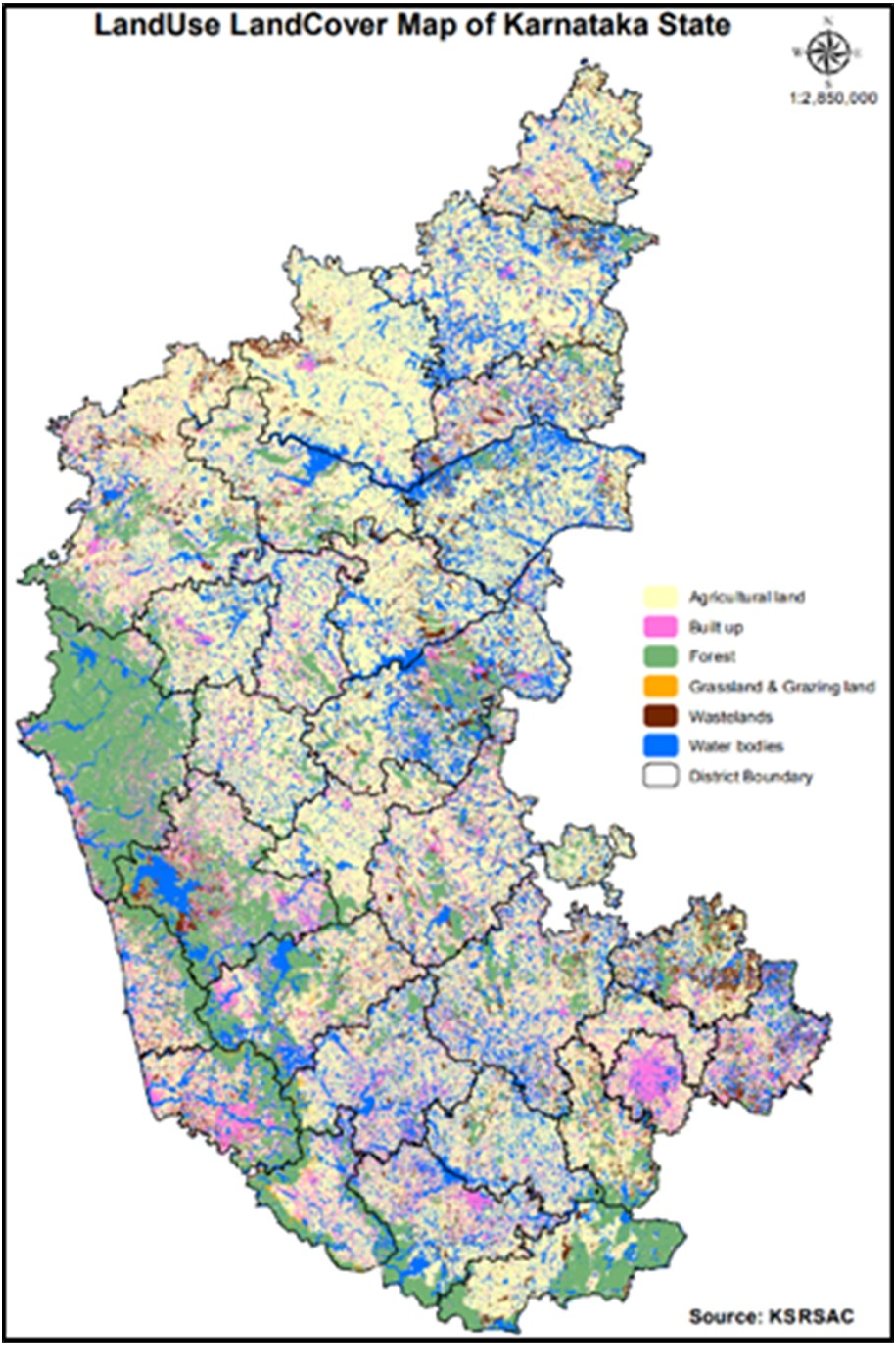

Fig. 2. Land use land cover map of Karnataka (Source: KSARSAC, GoK (29)).

In eqn. 1, the coefficient of interest is βk, which captures the effect of k independent variables used in the model. This model accounted for several supply-side factors, such as irrigation and access to credit, that could affect diversification and vary with time and across districts. Social variable, the share of land holdings owned by the SC and ST category in the total land holdings of the district, was also included based on the assumption that the disadvantaged social groups may have limited resource endowment to diversify their cropping pattern. Likewise, demand-side factors like the district's GDP and share of the urban population could affect crop diversification in agriculture. vi and δt denote district and time-fixed effects, respectively.

Specification of the regression model with land share under horticulture crops and its sub-categories as dependent variable

Second set of regressions, the following model was applied.

The fixed effects regression model for unit i and period t is mentioned below (Eqn. 2).

Yit= Xk.itβk + δt + vi + Ɛit ……………………….......(Eqn. 2)

Where,

Yit = response variable in terms of share of land under horticulture crops and sub-categories of horticulture, where i=1,2,3…. n and t=1,2,3…t

Xit= regressor variables for i=1,2,3…. n and t=1,2,3…t

βk= coefficients for the respective k regression variables (both independent and control variables) in Xi.

Ɛit =idiosyncratic error term with zero mean and constant variance where i=1,2,3…. n and t=1,2,3…t.

vi = group-specific error term (omitted variables constant over time for every i also known as fixed effects to induce unobserved heterogeneity in the model), where i=1,2,3…n 3.2.3.

Choice of estimation model and post estimation tests

For estimating β using the fixed-effects estimator, also known as the within estimator, using OLS (Ordinary Least Square) method to perform the estimation of eqn. 1 and 2. For a given entity or group with the same value of vi across all periods, analysing a fixed effects model involves estimating the coefficients β and the unit-specific effect vi for each unit i. The assumptions of the fixed effects estimator, which is the estimates, are conditional on the sample in that the vi are not assumed to have a distribution but are instead treated as fixed and one that can be estimated, which can lead to difficulty when making out-of-sample predictions. The robust Hausman test was used as a diagnostic test for model selection in the study (39-44). Moreover, the model for heteroscedasticity error after estimating the panel regression (fixed effects) model was tested using the modified Wald test for group-wise heteroskedasticity test. The clustered or robust standard errors account for correcting heteroscedasticity and autocorrelation. Robust standard errors were generated using robust techniques which was applied to the fixed effects regression model to obtain heteroscedasticity- robust standard errors instead of default standard errors to correct for the problem of heteroscedasticity in the model (41). The regression function includes the complete set of year dummies, aka fixed time effects, to control general trends in predictor variables and cross-individual correlation.

Results and Discussion

Descriptive analysis

Simpson's diversification index shows that agriculture in the state has witnessed a secular increase in diversification trend over the period of one and half decade till 2015 followed by a downward trend (Fig. 3).

The GIS maps (Fig. 4a) visualizes the proportion of horticultural land across Karnataka's since 2001-02, highlighting spatial shifts and intensity of high-value crop adoption over two decades. The crop diversification has changed at the district-level since 2001 (Fig. 4b). At the district level, indices of the crop diversification have stood at above 70 % for the last twenty years, with little difference in its value over the period. At the district level, Bagalkote, Belgaum, Mysore, Shimoga, Raichur and Uttara Kannada were the only districts that have reported an increase in crop diversification in 2001. Other districts have shown either decline or the same level of diversification over the period of two decades.

The area within cultivated land that is allotted to broad crop sector at the state level for the period 2001-02 to 2020-21 is shown in Fig. 5. At the state level, the share under horticulture land use has seen an increase from 13.58 % in 2001-02 to 17.58 % in 2020-21. Unlike cereals and oilseeds, which have experienced a decline in their share, pulse crops and commercial crops have shown steady growth over the period. A significant share of the area comes from grains and pulses, followed by horticulture crops.

The relation between diversification and horticulture land use at the district level using the data for the years 2001-02 to 2020-21 is shown in Fig. 6. Interestingly, the result shows that the relation between share of horticulture and diversification index is negative, underlining that districts are diversifying towards horticulture crops at the expense of overall diversification. In other words, districts are over time specializing in favour of horticulture crops. There are also some outliers too, showing that an increase in the share of land allotted to horticulture has the effect of improving the diversification index too.

District-wise trends of share of land allotted to horticulture in total cropped land over the study period, with most districts reporting an increase in share of land allotted to total crop land (Fig. 7a and 7b). Only seven districts out of 27 districts report a decrease in the share of area under horticulture crops over the period 2001 to 2016 (Fig. 7b).

Our analysis further explores trends of land use in the sub -classification of crops grown under the horticulture category at both state and district levels. Fig. 8 presents the state-level share of area under each sub-category of horticulture. At the state level, all crop categories show a slight increase in their share, except for plantation crops, which show a significant and continuous improvement from 5.73 % to 8.69 % of the total gross cropped area since 2001.

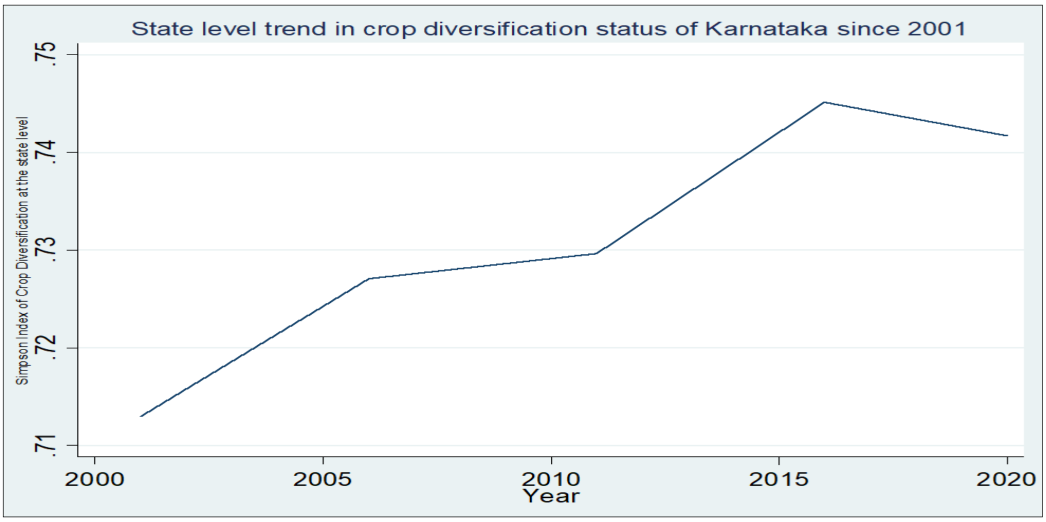

Fig. 3. State level trend in crop diversification status of Karnataka since 2001-02.

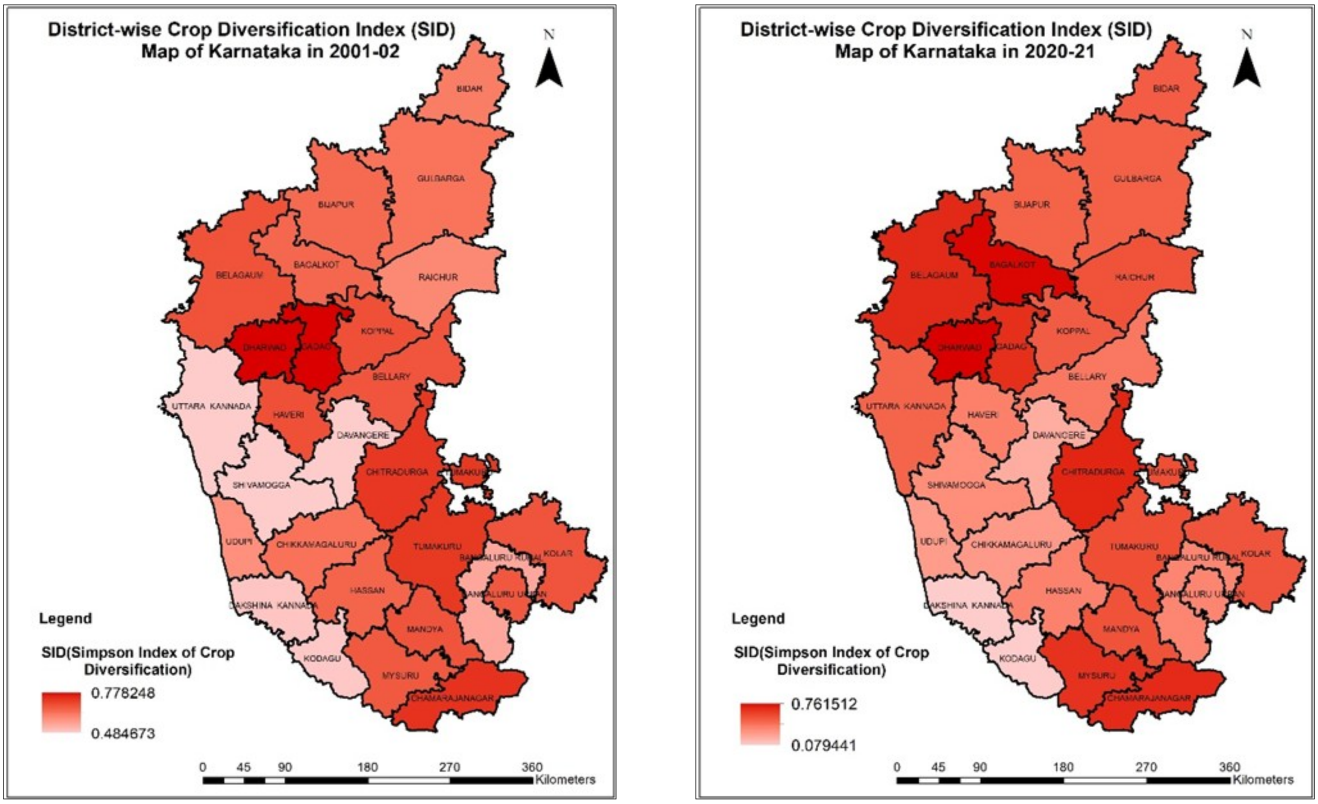

Fig. 4a. District-wise trend in crop diversification index of Karnataka in 2001-02 and 2020-21.

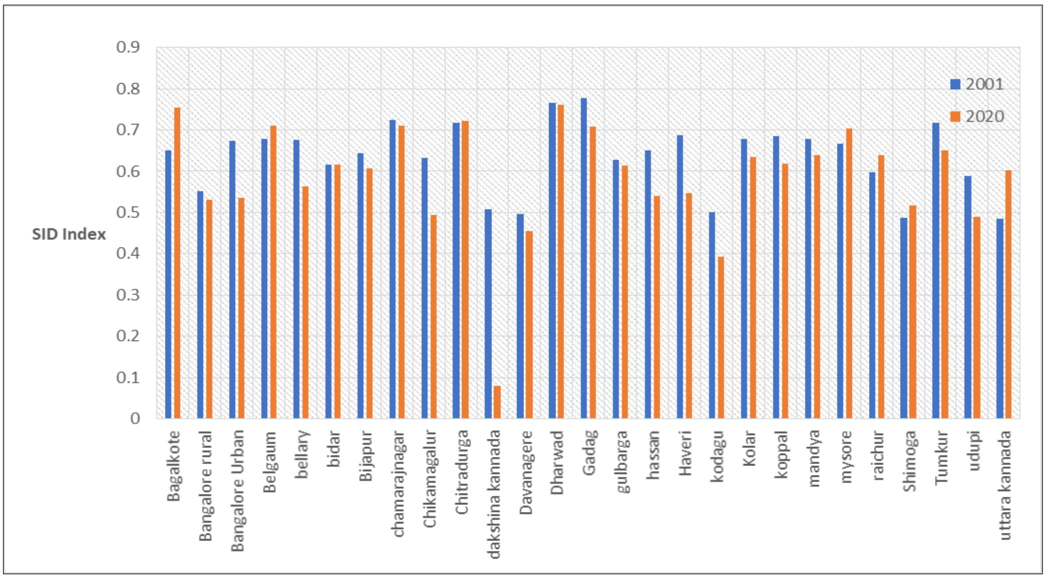

Fig. 4b. District-wise trend in crop diversification status of Karnataka since 2001-02.

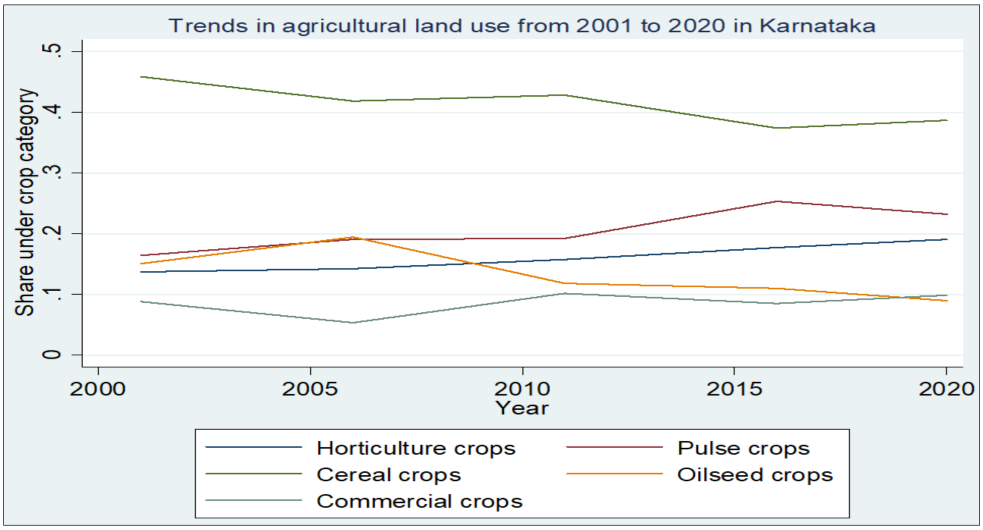

Fig. 5. State-level trend in agricultural land use from 2001 to 2020 in Karnataka.

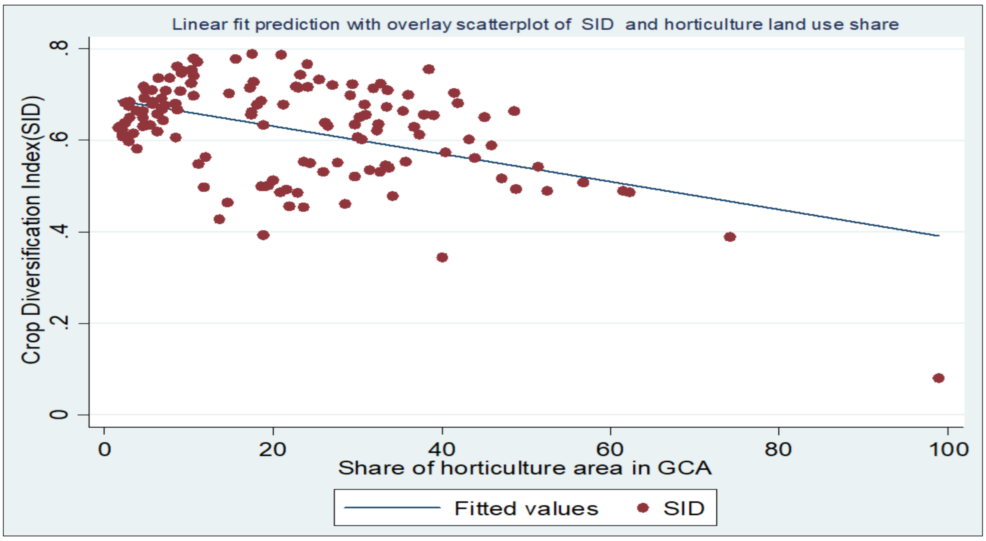

Fig. 6. Crop diversification index and percentage of land dedicated to horticulture in Karnataka.

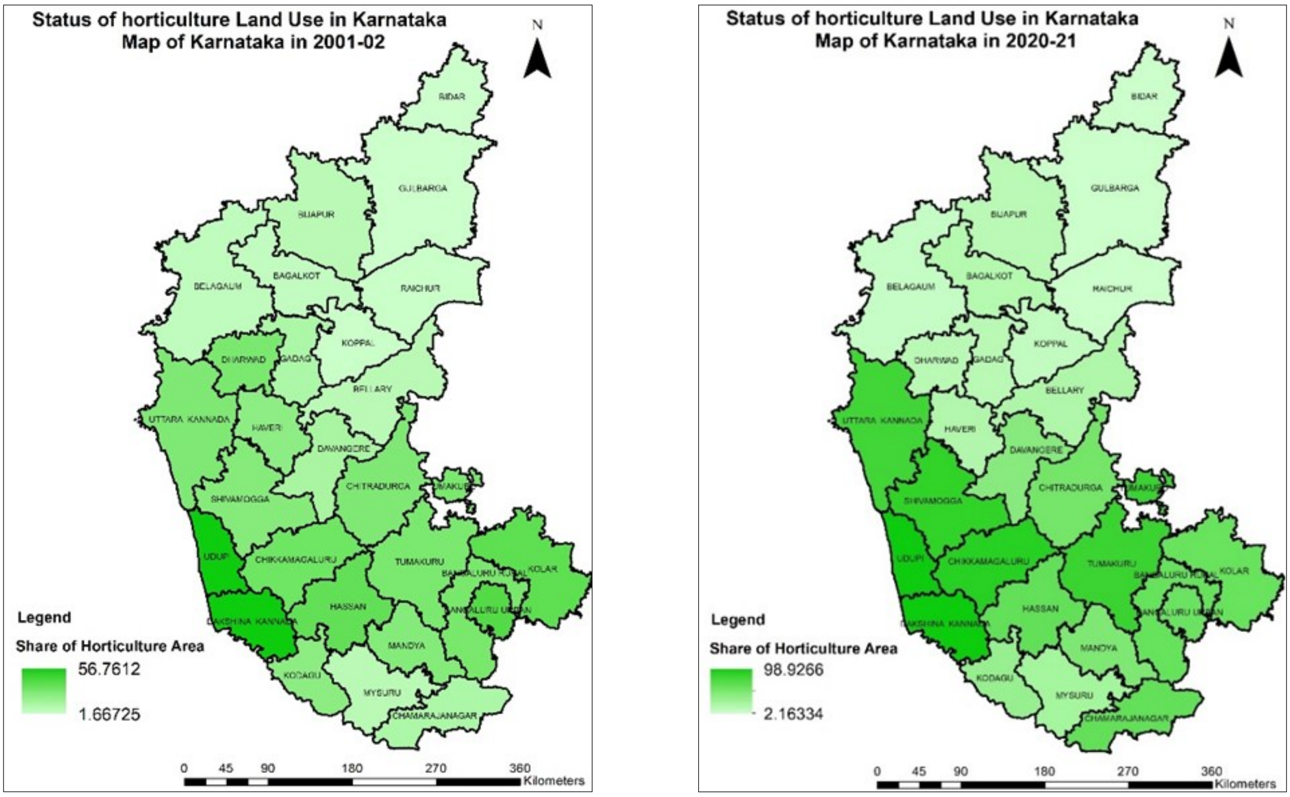

Fig. 7a. District-level share of land under horticulture in Karnataka in 2001-02 and 2020-21.

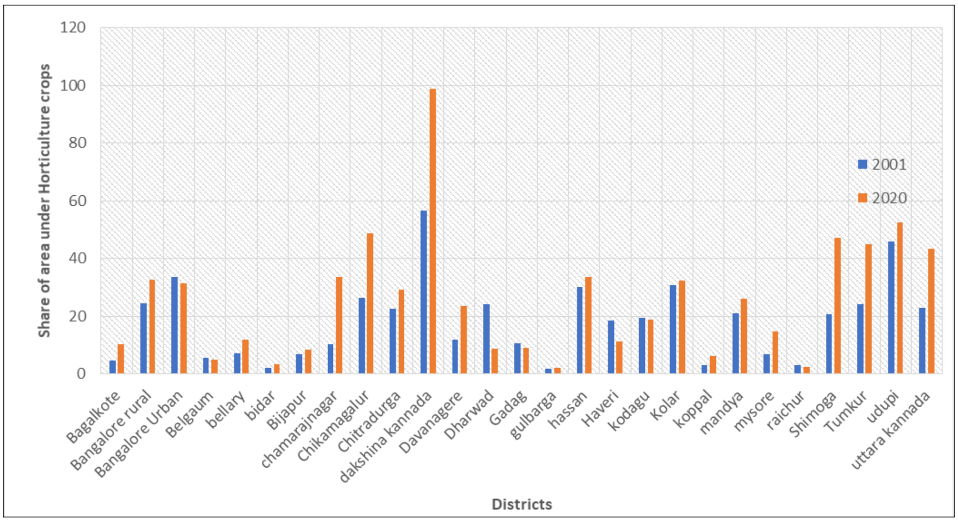

Fig. 7b. District-wise change in share of horticulture area from 2001 to 2020 in Karnataka.

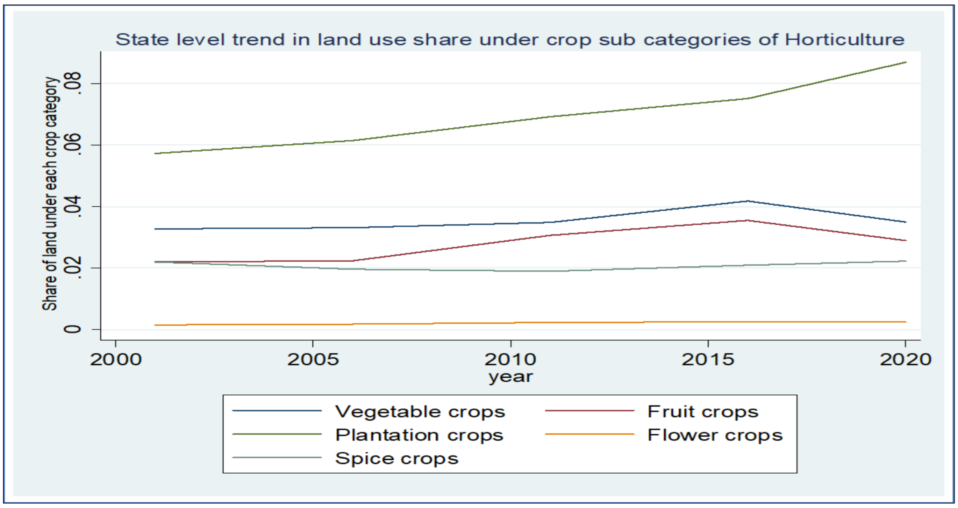

Fig. 8. State-level trend in crop sub-categories of horticulture in total cropped area.

Bagalkote, Gadag, Gulbarga, Bijapur and Koppal districts are primarily cultivated with vegetables (around 60 % or more) (Fig. 9). In contrast, plantation crops are the dominant choice in districts Mandya, Shimoga, Udupi, Uttara Kannada, Dakshina Kannada, Davanagere, Chikamagalur and Chitradurga. Notably, Bangalore Rural, Bijapur, Kolar and Chamaraj Nagar districts stand out as they are predominantly cultivated with fruit crops. These practical implications of our research findings are engaging and will be of interest to different stakeholders and policy makers. The descriptive statistics of the variables used in the regression exercise is shown in Table 4.

The compound growth rate of horticultural areas at the district level to understand the significance of horticulture cultivation over the last two decades was estimated (Table 5). All the districts except Bangalore Urban and Dharwad show a growth rate in the area, which indicates the significant growth of horticulture in Karnataka over the years.

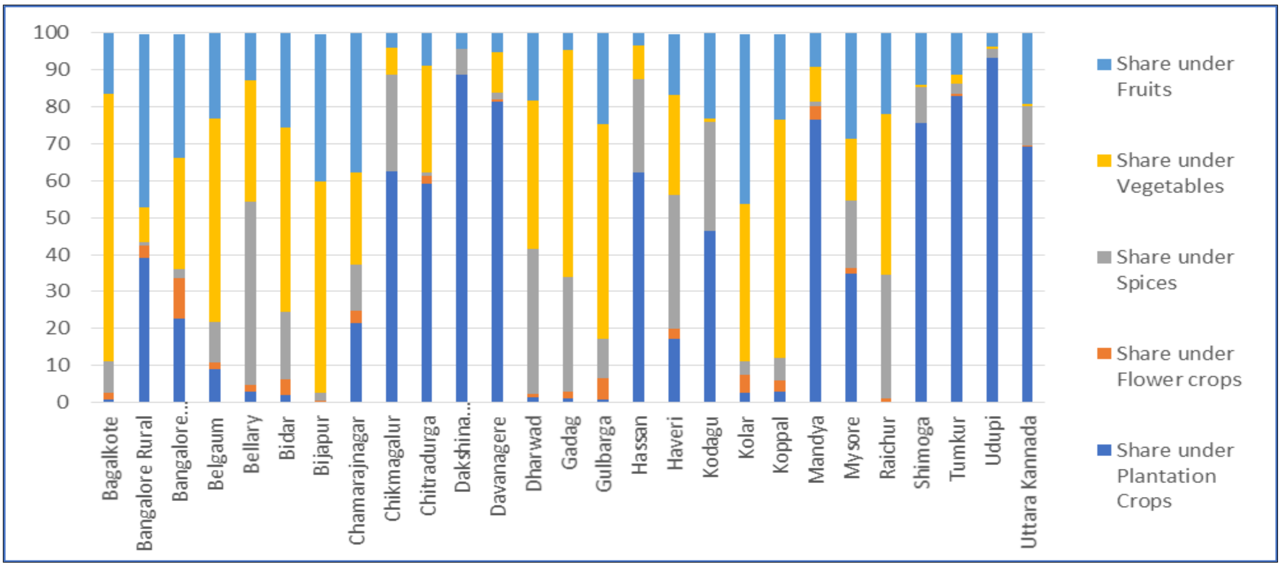

Fig. 9. District-wise share of sub-category crops in total horticulture area in 2020-21.

Table 4. Summary statistics of variables used in regression analysis

Variables	Mean	Standard deviation	Minimum	Maximum
Dependent variable				
Simpson index of crop diversification (index)	0.62	0.11	0.08	0.79
Share of area under horticulture crops (percentage)	22.14	16.83	1.67	98.93
Share of area under vegetable crops (percentage)	3.96	3.46	0.03	17.24
Share of area under plantation crops (percentage)	11.41	15.23	0.01	87.70
Share of area under fruits and flower crops (percentage)	0.04	0.04	0.003	0.23
Independent variables				
Population density per square km (number per square km)	428.38	746.75	132.93	5185.57
Per capita gross district domestic product (INR-Indian rupees*)	11.20	0.99	9.26	13.22
Road density (per 100 km^2)	36.56	13.06	14	76.01
Credit institutions (number of banks per 1000 km^2)	37.30	24.72	9.31	147.59
Average annual rainfall (cm)	116.42	101.61	34.46	471.42
Average annual temperature (°C)	25.52	1.89	19.87	29.76
Share of the irrigated area under the total cropped area (percentage)	44.12	53.92	0.3	100.0
Share of the urban population in the total population (percentage)	30.21	15.43	13.74	93.24
Share of land under marginal and small land holdings category (percentage)	48.43	19.08	17.75	100.0
Share of the non-agricultural area in the total geographical area (percentage)	8.98	9.15	2.20	57.69
Share of land holdings belonging to schedule caste (SC) and schedule tribe (ST)[1] social groups (percentage)	16.40	8.15	4.24	36.45

[1]ST and SC are terms used in the Indian Constitution to refer to specific tribal and caste groups that face social exclusion and are granted administrative and welfare privileges to help offset their disadvantage. ST and SC continue to be among the most socio-economically disadvantaged groups in India and have some of the lowest health outcomes in the country (45).

Table 5. Growth rates, average size of land holding and share of small and marginal land holdings under horticulture in Karnataka 2001-02 to 2020-21

District	Compound annual growth rate of horticulture area (%)	Average size of land holding in hectare (pooled time series data)	Share of landholdings area under small and marginal category (pooled time series data)
Bagalkote	6.36	2.20	32.19
Bangalore Rural	1.250	0.950	64.710
Bangalore Urban	-4.750	1.040	70.630
Belgaum	1.510	1.850	37.950
Bellary	5.700	2.000	32.580
Bidar	4.880	1.880	41.200
Bijapur	3.370	2.910	22.370
Chamarajanagar	5.370	1.040	70.660
Chikkamagalur	3.220	1.440	43.450
Chitradurga	2.400	2.010	35.940
Dakshina Kannada	2.890	0.890	57.060
Davanagere	3.810	1.520	46.930
Dharwad	-3.150	2.540	23.380
Gadag	1.170	2.500	27.510
Gulbarga	2.040	2.370	29.770
Hassan	1.390	0.980	64.960
Haveri	-0.760	1.810	44.490
Kodagu	2.140	2.450	21.880
Kolar	1.240	1.030	55.790
Koppal	6.370	2.140	34.480
Mandya	1.410	0.660	78.790
Mysore	4.060	0.930	74.700
Raichur	0.710	2.220	31.850
Shimoga	5.120	1.260	55.850
Tumkur	3.440	1.560	43.620
Udupi	0.790	0.770	60.410
Uttara Kannada	4.380	0.820	67.930

A linear fit prediction plot with an overlay scatterplot for the horticulture area, when regressed separately on land under small and marginal farms, GDP, rainfall, and irrigated area (Fig. 10a to 10d), indicated that these variables significantly influence horticultural development. The fitted line for land under small and marginal category shows a positive relation between share of horticulture and smallholder presence in a district. However, there are outliers showing that there are districts with small share of small and marginal lands showing high share of land allotted to horticulture crops and vice versa. District GDP per capita, and rainfall positively influence the area under horticulture. Surprisingly, the area share under irrigation looks different from the general assumption of a positive relationship between the two variables, which might be because crops like cereal crops are preferred when provided with irrigation. The relationship after accounting for other determinants of diversification (both observed and unobserved) in land allotted for horticulture crops in Karnataka was analysed.

Panel data regression: Fixed effects model

Each regression model used in the study is chosen after testing for group-wise heteroscedasticity and serial autocorrelation errors (40, 41). It is also tested for the functional form of the model specification using the Ramsey reset test (42). Modified Wald test for group-wise heteroskedasticity in fixed effect regression model could reach the level of significance at one per cent level to reject the null hypothesis of constant variance for all the districts. In this view, the diagnosis of the presence of heteroskedasticity led to the use of robust standard errors in the model. The robust standard errors reported in the model are the same as those obtained by clustering on the panel variable on districts and clustering on the district variable produces an estimator of the VCE that is robust to cross-sectional heteroskedasticity and within-panel (serial) correlation (38).

The robust Hausman test results consistently reject the null hypothesis, underscoring the preference for the fixed-effects model. Given the short panel with T = 5 and N = 27, there's no need to test for the problem of the predictor variables' non-stationarity in the model. This underscores the significance of the fixed-effects model in the context of our panel data characteristics.

After thorough testing for the joint statistical significance of the time variable (year), time effects were included in the model. This inclusion is justified by testing the Wald test to ensure their importance among the other predictor variables. They are included in two models, including the share of land

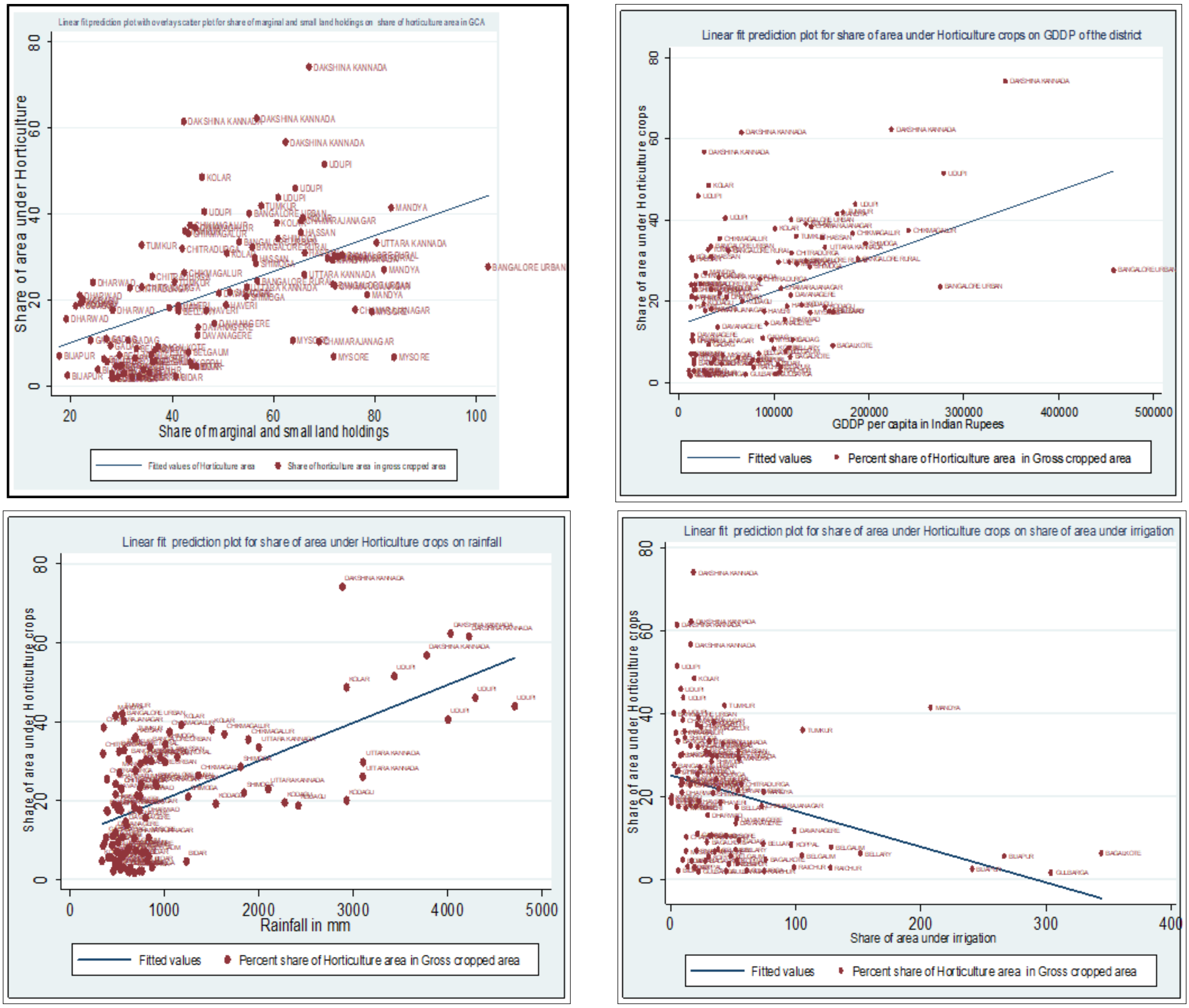

Fig. 10a-d. Linear fit prediction plots with an overlay scatter plot of share of small and marginal land holdings under horticulture, GDDP (gross district domestic product), rainfall and irrigated area share respectively.

under horticulture crops and plantation crops, as DV.

The results of the estimated fixed effects regressions using panel data with districts as group variables and years as time variables are reported in Table 6 and 7. It presents the predictor variables included in the model and the estimated coefficients with their robust standard error and significance level. Table 6 shows the estimation of the result of the eqn. 1, which deals with the estimation of determinants of SID as DV. Table 7 shows the result estimation of eqn. 2 with share of different land use in the gross cropped area of the district as DV, namely, horticulture crops (comprised of all the five crop categories) along with different sub-segment of crop categories under horticulture including plantation crops, vegetable crops, fruit crops area and flower crops.

The regression results using SID as DV show that while share of non-agricultural area has a negative effect on diversification, population density and credit institutions have a positive and significant effect in the model. Higher share of non-agricultural land may entail greater pressure on land, prompting farmers to specialize rather than diversify to get higher return from the land. However, high population density may imply higher availability of labour on demand and easy credit availability due to presence of credit institutions which may relax the supply constraint, with positive effect on diversification.

In Table 7, the result of eqn. 2 on the determinants of share of land allotted towards horticulture and different crop sub-sectors within the horticulture segment was shown. Among the factors, variables such as population density and the district's GDP per capita have significant effect on the share of land allotted under horticulture crops and other crop sub - sectors within it. Population density has negative effect on horticulture crops, plantation crops and vegetable crops. While high population density may relax the constraint of labour supply, limited available land due to population pressure may make it difficult to divert limited land to new crops in demand. However, higher district GDP per capita has favourable effect on the share of land allotted to each crop sector due to higher demand. One major demand side factor, such as gross GDP per capita of the district, influences the share of horticulture area positively, including districts with more GDP per capita will have more share of land under horticulture in total gross cropped area, which has an expected sign (46). If there is a one per cent increase in the gross GDP per capita of the district, there will be a 0.064 % increase in the share of land under horticulture in the total gross cropped area.

Surprisingly, urbanization as indicated in the share of population living in urban areas of a district, has positive effect on the area allotted for plantation crops but have negative effects on vegetables and fruits and flowers. Higher push for urbanization may create a competing demand for land (47), with negative effect on land allotted for high value commercial crops. However, the positive relation between plantation and urbanization is less straightforward. The same may be prompted by the plantation industry itself creating urban clusters in and around the industry.

Among the supply side factors, the number of credit institutions in a region, indicating accessibility of credit, has a positive sign for fruits and vegetables and negative sign for plantation crops. Plantation crop requires a big volume investment that are less dependent on local credit availability. However, the spread of credit institutions in a region may relax the credit constraints of the competing crops such as fruits and flower, which are more dependent on the local availability of

Table 6. Fixed effects estimate of district-level regressions using Simpson Index of Diversification (SID) as dependant variable[2]

Variables	Simpson index of crop diversification (SID)
Share of the non-agricultural area in the total geographical area (%)	-0.0266*
Share of land holdings belonging to SC and ST category (%)	0.0026 (0.0025)
Share of urban population (%)	-0.0076 (0.0055)
Share of irrigated area (%)	0.0001 (0.0001)
Population density per km^2	0.0002** (0.0001)
Log value of per capita GDP (Rs.)	-0.0162 (0.0309)
Road density (Km)	-0.0012 (0.0012)
Credit institutions (Number)	0.0007** (0.0003)
Rainfall (Cm)	0.0002 (0.0001)
Temperature (°C)	-0.0004 (0.0046)
Average land size (Ha)	-0.0438 (0.0519)
Year fixed effects	Yes
Constant	1.1821*** (0.3441)
R-squared	0.46

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

[2]robust standard errors in parentheses

Table 7. Fixed effects estimate of district-level regressions[3] using share under total horticulture and its categories[4] as dependant variable

Variables	Horticulture area	Plantation crops	Vegetable crops	Fruits and flower crops[5]
Share of urban population	0.7838	1.0525**	-0.2439**	-0.1932**
	(0.7057)	(0.4715)	(0.0910)	(0.0916)
Share of irrigated area	0.0115	0.0092*	-0.0014	0.0003
	(0.0082)	(0.0047)	(0.0026)	(0.0028)
Population density	-0.0103***	-0.0079***	-0.0020**	-0.0001
	(0.0027)	(0.0017)	(0.0010)	(0.0005)
GDP per capita (log)	6.4258*	4.6640**	0.9973*	1.0632
	(3.4035)	(2.0979)	(0.5730)	(0.7125)
Road density	-0.0339	0.0925	-0.0555	-0.0337
	(0.1590)	(0.0735)	(0.0449)	(0.0495)
Credit institutions	-0.0550	-0.0787***	-0.0113	0.0478***
	(0.0370)	(0.0238)	(0.0132)	(0.0139)
Rainfall (cm)	0.0061	-0.0180	0.0052	0.0031
	(0.0290)	(0.0122)	(0.0082)	(0.0071)
Temperature (°C)	-0.3517	-0.0654	0.1345	-0.1015
	(0.5228)	(0.3407)	(0.1992)	(0.1226)
Small and marginal land (%)	0.0787	0.0814	0.0539	-0.0178
	(0.1350)	(0.0675)	(0.0515)	(0.0426)
Year fixed effects	Yes	Yes	No	No
Constant	-55.3660	-63.1060**	-3.1165	0.6577
	(37.5696)	(24.1158)	(6.3827)	(4.5168)
R-squared	0.41	0.59	0.13	0.26

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ f

[3]robust standard errors in parentheses

[4]categories excludes spice crops category as it fails to be included as a panel regression model

[5]joined fruit and flower crops as single category

credits. Share of irrigated area has a positive effect on land allotted to plantation crops but has no significant effect on the land allotted for other crops. The land size variable, even though it has non-significant value in the model, its direction suggests a tendency among small and marginal farmers to diversify into horticultural crops particularly plantation and vegetable crops, and similar results have been reported in the past (39). However, this trend does not extend to fruit and flower crops.

Conclusion

This study reveals that while governments and donors have emphasized diversifying smallholder agriculture by moving away from cereals and toward high-value horticultural crops, the drivers of this shift extend beyond household-level factors. Using district-level panel data from Karnataka (2001–2021), our analysis highlights the critical role of meso-level determinants such as population density, credit access, irrigation infrastructure, GDP, and urbanization in shaping up diversification decisions. Moreover, our findings indicate that diversification dynamics are context-dependent: regions with higher initial diversification levels exhibit diminishing marginal gains, and improvements in credit access can have contrasting effects across horticultural sub-sectors (e.g., plantations versus fruits and vegetables).

These insights underscore the importance of multi-level approaches for policy and program design. Interventions must acknowledge the substantial influence of district-level conditions that may not be captured through household surveys alone. Tailoring financial, infrastructural, and institutional support to fit the specific agrarian context and crop sub-sector is essential. In essence, smallholder diversification toward high-value crops can be best supported by localized, crop-sensitive strategies that integrate both micro (household) and meso (district) perspectives. Policymakers and development agencies must recognize the heterogeneity of smallholder contexts and avoid one-size-fits-all strategies in favour of nuanced, data-driven policies. In summary, tailored interventions, informed by comprehensive multi-level analyses, are essential to fostering sustainable and remunerative diversification towards different crop segments in smallholder agriculture.

Acknowledgements

The authors acknowledge the support for this study from Christ (Deemed to be University) in Bangalore, Karnataka. This study has been conducted as a part of the Ph.D. thesis work done at Christ (Deemed to be) University, Bengaluru, India. The authors acknowledge the provision of data and reports from the Directorate of Economics and Statistics, Department of Agriculture and Department of Horticulture, GoK and IMD, Pune. The authors also acknowledge the thoughtful and constructive feedback from the anonymous peer reviewers, which

significantly enhanced the quality and clarity of this manuscript.

Authors' contributions

RC conceptualised the idea, reviewed the literature, collected and analysed the data and conducted data analysis. RS designed and conceptualised the research idea, suggested the econometric model, refined the empirical strategy, coordinated research, analysed the data and edited the document. ME helped in discussion of results, coordination of the research and editing of the document. UBK helped in drafting and editing the paper. JP helped in preparing the conclusions and policy implications part of the document. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process: During the preparation of this work the authors used Grammarly tool in order to enhance language clarity and grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

1. Ruben R. What smallholders want: Effective strategies for rural poverty reduction. Sustainability. 2024;16(13):5525. https://doi.org/10.3390/su16135525
2. Joshi PK, Gulati A, Birthal PS, Tewari L. Agriculture diversification in South Asia: Patterns, determinants and policy implications. Econ Pol Weekly. 2004;12:2457-67.
3. Reardon T, Timmer CP, Minten B. Supermarket revolution in Asia and emerging development strategies to include small farmers. Proc Nat Acad Sci. 2012;109(31):12332-37. https://doi.org/10.1073/pnas.1003160108
4. Dolan C, Humphrey J. Governance and trade in fresh vegetables: The impact of UK supermarkets on the African horticulture industry. J Dev Stud. 2000;37(2):147-76.
5. Narayanan S. Profits from participation in high value agriculture: Evidence of heterogeneous benefits in contract farming schemes in Southern India. Food Policy. 2014;44:142-57. https://doi.org/10.1016/j.foodpol.2013.10.010
6. Government of India. The Economic Survey -2022-23. Ministry of Finance. 2023. Available from: https://www.indiabudget.gov.in/budget2023-24/economicsurvey/index.php
7. Bisht IS, Rana JC, Pal Ahlawat S. The future of smallholder farming in India: Some sustainability considerations. Sustainability. 2020;12(9):3751. https://doi.org/10.3390/su12093751
8. Government of India. Situation assessment survey of agricultural households, 77th Round. National sample survey office, Ministry of Statistics and Programme Implementation. 2019.
9. Government of Karnataka. Directorate of Economics and Statistics. 2024.
10. Kennedy J, King L. The political economy of farmers' suicides in India: Indebted cash-crop farmers with marginal landholdings explain state-level variation in suicide rates. Glob Health. 2014;10:1-9.
11. Government of India. The national crime records bureau (NCRB) data report. 2023.
12. Birthal PS, Roy D, Negi DS. Assessing the impact of crop diversification on farm poverty in India. World Dev. 2015;72:70-92. https://doi.org/10.1016/j.worlddev.2015.02.015
13. Kumar S, Gupta S. Crop diversification towards high-value crops in India: A state level empirical analysis. Agric Econ Res Rev. 2015;28(2):339-50.
14. Anuja AR, Kumar A, Saroj S, Singh KN. The impact of crop diversification towards high-value crops on economic welfare of agricultural households in eastern India. Curr Sci. 2020;118(10):1575-82.
15. Government of India. Report of the inter-ministerial committee constituted in April, 2016 on "Strategy for doubling of farmers income (DFI). Ministry of Agriculture & Farmers Welfare. 2022. Available from: Press Release: Press Information Bureau (pib.gov.in)
16. Singh RP. Horticultural (high value agricultural) crops diversification in eastern India: II–Employment opportunities and income generation strategies. Int J Innov Hortic. 2013;2(1):28-43.
17. Government of India. Agricultural statistics at a glance-2021. Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Economics & Statistics. 2021. Available from: https://ruralindiaonline.org/or/library/resource/agricultural-statistics-at-a-glance-2021/
18. Gupta PR, Joshi PK. Agricultural research for sustainable productivity growth in India. Transforming Indian agriculture-India. 2013.
19. Tsusaka TW, Otsuka K. The changing effects of agro-climate on cereal crop yields during the green revolution in India, 1972 to 2002. J Sustain Dev. 2013;6(4):11.
20. Aggarwal N, Jain S, Narayanan S. The long road to transformation of agricultural markets in India: Lessons from Karnataka. Econ Pol Weekly. 2017;47-55.
21. Potapov P, Turubanova S, Hansen MC, Tyukavina A, Zalles V, Khan A, et al. Global maps of cropland extent and change show accelerated cropland expansion in the twenty-first century. Nature Food. 2022;3(1):19-28.
22. Su S, Zhou X, Wan C, Li Y, Kong W. Land use changes to cash crop plantations: Crop types, multilevel determinants and policy implications. Land Use Policy. 2016;50:379-89. https://doi.org/10.1016/j.landusepol.2015.10.003
23. Anuja AR, Shivaswamy GP, Ray M, Singh KN. Pattern of crop diversification and its implications on undernutrition in India. Curr Sci. 2022;122(10):1154.
24. India Meteorological Department. IMD Pune. 2024. Available from: http://www.imdpune.gov.in
25. Government of India. Office of the Registrar General & Census Commissioner, India. Census of India 2011. Available from: https://censusindia.gov.in/
26. Public Works, Ports & Inland Water Transport Department, Government of Karnataka. 2024. Available from: https://kpwd.karnataka.gov.in/english
27. State Level Bankers' Committee, Karnataka. SLBC Karnataka. 2024. Available from: https://slbckarnataka.com/
28. Department of Horticulture, Government of Karnataka. 2024. Available from: https://horticulturedir.karnataka.gov.in/en
29. Karnataka State Remote Sensing and Applications Cent *K-GIS* portal. 2024. Available from: https://kgis.ksrsac.in/kgis1/portal.aspx
30. Acharya SP, Basavaraja H, Kunnal LB, Mahajanashetti SB, Bhat AR. Crop diversification in Karnataka: An economic analysis. Agric Econ Res Rev. 2011;24(2):351-57.
31. Das A, Kimoto K, Ravi Kumar M, Umakanth R, Sengupta, D, Vishwanth HR. Land use sustainability of agricultural zones. In:

Himiyama Y, editor. Exploring sustainable land use in monsoon Asia. Springer: Singapore; 2018. p. 103-135. https://doi.org/10.1007/978-981-10-5927-8_6

32. Singha K, Chakravorty A. Crop diversification in India: A study of maize cultivation in Karnataka. Sci J Rev. 2013;2(1):1-10.
33. Rao PP, Birthal PS, Joshi PK. Diversification towards high value agriculture: Role of urbanisation and infrastructure. Econ Pol Weekly. 2006;27:47-53.
34. Mithiya D, Mandal K, Datta L. Trend, pattern and determinants of crop diversification of small holders in West Bengal: A district-wise panel data analysis. J Dev Agric Econ. 2018;10(4):110-19. https://doi.org/10.5897/JDAE2018.0921
35. Birthal PS, Joshi PK. Smallholder farmers' access to markets for high-value agricultural commodities in India (6-4). In: Pinstrup-Andersen P, Cheng F, editors. Case studies in food policy for developing countries: Domestic policies for markets, production, and environment. Cornell University Press: New York; 2009. p. 51-60. https://doi.org/10.7591/9780801466373-007
36. Birthal PS, Hazrana J, Negi DS. Diversification in Indian agriculture towards high value crops: Multilevel determinants and policy implications. Land Use Policy. 2020;91:104427. https://doi.org/10.1016/j.landusepol.2019.104427
37. Pesaran MH. General diagnostic tests for cross-sectional dependence in panels. Empir Econ. 2021;60(1):13-50. https://doi.org/10.1007/s00181-020-01875-7
38. Felix KT, Ramappa KB. An economic analysis of crop diversification and dynamics of cropping pattern in Karnataka, India. Humanit Soc Sci Commun. 2023;10(1):1-9. https://doi.org/10.1057/s1599-023-02078-y
39. Schaffer M, Stillman S. XTOVERID: Stata module to calculate tests of overidentifying restrictions after xtreg, xtivreg, xtivreg2, xthtaylor. Statistical Software Components , Department of Economics, Boston College. 2016. Available from: https://EconPapers.repec.org/RePEc:b4oc:bocode:s456779
40. Greene W. Estimating econometric models with fixed effects. Department of Economics, Stern School of Business, New York University. 2001. Available from: http://repec.org/usug2020/Wooldridge_u20.pdf
41. Cameron AC, Miller DL. A practitioner's guide to cluster-robust inference. J Hum Resour. 2015;50(2):317-72. https://doi.org/10.3368/jhr.50.2.317
42. Ramsey JB. Tests for specification errors in classical linear least-squares regression analysis. J Royal Stat Soc Series B: Stat Methodol. 1969;31(2):350-71. https://doi.org/10.1111/j.2517-6161.1969.tb00796.x
43. Wooldridge JM. Correlated random effects methods for panel data models with heterogeneous time effects. 2020 UK Stata Conference, Department of Economics Michigan State University. 2020. Available from: http://repec.org/usug2020/Wooldridge_u20.pdf
44. Arellano M. Computing robust standard errors for within-groups estimators. Oxf Bull Econ Stat. 1987;49(4):4006. https://doi.org/10.1111/j.1468-0084. 1987.mp49004006
45. Balarajan Y, Villamor E, Subramanian SV. Decomposing malnutrition inequalities between scheduled castes and tribes and the remaining Indian population. Int J Epidemiol. 2011;40(2).
46. Birthal PS, Joshi PK, Roy D, Thorat A. Diversification in Indian agriculture toward high-value crops: The role of small farmers. Can J Agric Econ. 2013;61(1):61-91.
47. Radhika C, Mahesh E, Sutradhar R, Udaya Bhaskar K. Trends and direction of land use change in the perspective of urbanization in Karnataka: A district level study. Indian J Agric Res. 2024:1-9.

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.