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Is crop diversification vulnerable to climate, agricultural and socio-economic factors in Himachal Pradesh, India?

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Crop diversification is essential for long-term farm income, rural livelihood and agricultural development in Himachal Pradesh (HP), India. The present study aims to examine the effect of climate, agricultural and socio-economic factors on crop diversification. Sirmaur district was found to be diverse, Kangra and Mandi districts were highly diversified, but Solan district was highly specialized in agriculture in HP. The fixed effects were found to be significant, indicating the role of farm-level changes in agronomic and cropping practices as a result of climate change. Crop diversification was led by population density, percentage of marginal and small farmers, cropping intensity, cultivators, marginal workers and total main workers. The important climate parameters like rainfall and minimum temperature, as well as other factors such as irrigation intensity and food crop productivity, had a negative impact on crop diversification, implying crop specialization.

Keywords: Agricultural development, climate change, crop diversification, panel regression, socio-economic factors.

CLIMATE change has become a major threat to the long-term development of agriculture and rural livelihood around the world. The regular occurrence of extreme events has a negative impact on agricultural production and food supply. It also causes losses to productive assets, exacerbates rural poverty, forces out-migration, reduces demand for industrial products and services and causes overexploitation of natural resources such as water, land and forests. In India, extreme drought reduces household income by 25–60% and increases poverty by 12–33% (ref. 1). Despite using multiple risk-coping strategies, farm households are unable to recover their loss of assets just after an extreme event[2]. Farmers take various adaptation steps to address development risks depending on their risk aversion, access to weather information and the availability of resources for adoption. Indian agriculture is highly vulnerable to climatic shocks due to its reliance on rainfall. Rainfed agriculture accounts for roughly 45% of the total cropped area in the country, and evidence suggests that rainfed production

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systems are more vulnerable to rainfall and temperature shocks[3]. The frequency of climatic shocks in India has recently increased and is expected to rise further in the future[4]. Diversification of agriculture into high-value crops and the availability of non-farm job opportunities have helped small landholders increase their incomes and break the cycle of poverty, according to experiences gained in other developing countries[5]. Production of high-value crops such as fruits increased by 130.39% between 2001–02 and 2020–21, while that of vegetables increased by 132.11% (ref. 6). Farmers are gradually shifting to high-value commodities, particularly fruits and vegetables, implying that these have enormous potential to increase smallholder income levels and boost the productivity of scarce resources[7,8]. Crop diversification towards high-value cash crops, including fruits and off-season vegetables, consistent with a region's comparative advantage, is proposed as a viable solution to stabilize and boost farm incomes, increase job opportunities, and preserve and enhance natural resources, primarily land and water[9]. Micro-level experience also demonstrates that diversification through high-value crops is not only economically beneficial, but also reduces stress on the natural resource base[10,11]. Crop diversification is an important issue for agricultural development in Himachal Pradesh (HP), India, which has an abundance of natural resources[12]. The proximity of farmlands to the roadside, availability of sufficient family labour and irrigation facilities in HP were important factors that led farmers to cultivate high-value cash crops and allowed them to implement yield-enhancing practices and use inputs such as seeds of high-yielding varieties. Crop diversification is higher among marginal farmers[13] and agricultural diversification towards high-value crops is pro-smallholder, with smallholders playing a proportionally larger role in growing vegetables versus fruit at the national level[14]. Addressing challenges like adverse climatic conditions, irrigation infrastructure, labour availability and food crop productivity are critical to achieving faster, more efficient and sustainable agricultural growth for accelerating the pace of structural transformation in the study area, which is heavily dependent on agriculture and lacks the technological capabilities and financial resources to address emerging challenges. The present study proposes to assess the extent of crop diversification and examine the vulnerability of different determinants, including climate, agricultural and socio-economic factors.

This study is based on secondary data and a panel dataset from seven districts of HP during 1991–2020. The data were compiled from the official records of the Department of Agricultural and Statistics, Government of Himachal Pradesh[15]. Initially, 25 variables were considered for the study, which was reduced to 12 using principal component analysis, revealing the significant influence on crop diversification. Crop diversification index was measured by taking into account the area under all food and cash crops in order to assess the level of agricultural diversification. The spatial variation determinants of crop diversification were studied using panel data models, fixed and random effects models, which allow for lowering bias due to omitted variables and aid in controlling unobserved disturbances associated with crop diversification. The selection between fixed and random effects models is made using Hausman specifications, which examine whether the unique errors (μ_i) are correlated with the regressors.

The fixed effect model can be represented as follows:

$$\begin{aligned}\text{CDI}_{it} = {} & \alpha_0 + \beta_1 \text{ Maximum temperature}_{it} \\ & + \beta_2 \text{ Minimum temperature}_{it} + \beta_3 \text{ Rainfall}_{it} \\ & + \beta_4 \text{ Rural population density}_{it} \\ & + \beta_5 \text{ Marginal and small farmers}_{it} \\ & + \beta_6 \text{ Cropping intensity}_{it} \\ & + \beta_7 \text{ Irrigation intensity}_{it} \\ & + \beta_8 \text{ Cultivators}_{it} \\ & + \beta_9 \text{ Marginal workers}_{it} \\ & + \beta_{10} \text{ Total main workers}_{it} \\ & + \beta_{11} \text{ Food crop productivity}_{it} \\ & + \beta_{12} \text{ Non-food crop productivity}_{it} + \varepsilon_{it}.\end{aligned}$$

The study period was divided into three different decades for estimating the crop diversification index across districts, namely 1991–2000 (decade I), 2001–2010 (decade II), 2011–2020 (decade III) and 1991–2020 (overall). Heat-map figures were used to depict the crop diversification scenario across all districts in HP (Figure 1).

Using Jenks natural breaks classification method, the crop diversification index was classified into five classes for the study period: low diversified, moderately diversified, medium diversified, highly diversified and highly diversified districts in HP. Solan district was found to be highly specialized in farming during all the decades and the whole study period. The study further revealed that the Bilaspur district was in the medium diversified group during the decadal scenario as well as the overall period of study. On the other hand, the Kangra and Mandi districts were highly diversified in the second and third decades and the overall study period. However, diversification has increased in the Kangra district with respect to time. The Hamirpur and Una districts had shifted from diversified agriculture to specialized farming during the first to third decade. On the contrary, Sirmaur district reported an increasing trend in diversification and was also a highly diversified district in HP (Figure 1).

Before analysing crop diversification, we checked whether the determinants were free of unit roots or not. Fisher-type unit root test was used to analyse the 30 years' panel data. The inverse chi-square and modified inverse chi-square *P*-values for all variables were less than 0.05. This confirms that there are no unit roots in any of the variables.

Table 1 presents the Breusch–Pagan test, skewness and kurtosis decomposition of LM-test of variables. Heteroscedasticity, skewness and kurtosis were not found in the data, according to the diagnostic test. The skewness and

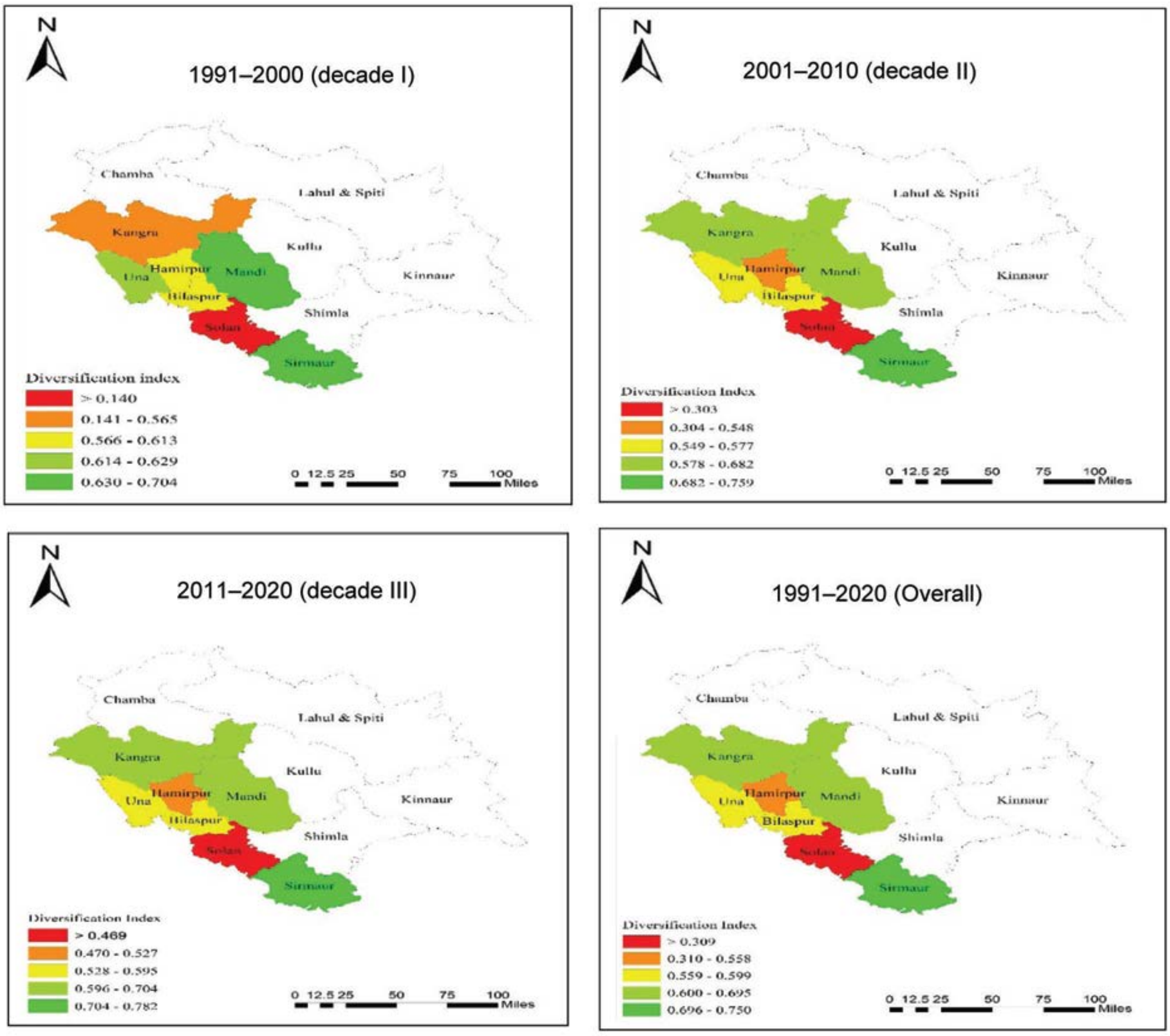

Figure 1. Crop diversification scenario.

Table 1. Breusch–Pagan, skewness and kurtosis test

Source	χ^2	*P*-value
Heteroscedasticity	85.05*	0.000
Skewness and kurtosis	21.38*	0.000

*Significant at the 0.01 level.

kurtosis results show that the data were normally and symmetrically distributed because the *P*-value was less than 0.05%.

The Hausman test was used to determine whether a fixed or random effects model should be considered for further analysis. Table 2 presents the results. The null hypothesis that the random effects model is more appropriate is rejected with $P = 0.00$. The fixed effect model, on the other hand, necessitates some diagnostic testing.

Table 3 shows the results of the fixed effects model using panel data regression. District fixed effects were found to be significant for diversification, indicating that including spatial fixed effects in panel data models is important for controlling time-invariant, location-specific characteristics that may be correlated with the variables. The time-fixed effects were also significant, indicating the importance of farm-level changes in agronomic and cropping practices due to climate change. The coefficients of population density, percentage of marginal and small farmers, cropping intensity, cultivators, marginal workers and total main workers were found to be significant with the expected signs of crop diversification, implying that these factors enhance the crop diversification in the Himalayan region. Socio-economic factors such as population density, percentage of marginal and small farmers, and percentage of marginal and total main workers were the primary sources of farm labour, and timely availability of farm labour would facilitate the production of a larger number of crops during that season. The impact of weather variables revealed that an increase in rainfall and the minimum temperature had a significant negative impact on crop diversification,

Table 2. Hausman test

Hypothesis	Hausman	Test statistics	*P*-value	Hypothesis
H_0 = Fixed effect model H_1 = Random effect model	χ^2	131.05*	0.001	H_0 was selected

*Significant at the 0.01 level.

Table 3. Estimates of fixed effects model

	Estimates		
Variables	Coefficient	*t*-value	*P*-value
TMIN (°C)	–0.0060560***	–1.51	0.13
TMAX (°C)	0.0049019	1.11	0.27
AR (mm)	–0.0000550*	–3.51	0.00
POPD (persons/km^2)	0.0014042*	3.97	0.00
MSF (%)	0.0076642*	–2.86	0.01
IRRI (%)	–0.0021349*	–2.60	0.01
CRII (%)	0.0025597*	3.11	0.00
CULT (nos)	0.0000008**	–2.24	0.03
WORKR (nos)	0.0000017*	5.12	0.00
TWORKR (Nos)	0.0000010*	–3.57	0.00
FCP	–0.0138707***	–1.75	0.08
NFCP	0.0040762	1.05	0.29
Intercept	0.8898675*	3.51	0.00
Time	Yes	–	–
District	Yes	–	–

***,** and *Significant at 0.15%, 0.05% and 0.01% respectively; TMIN, Minimum tempreture; TMAX, Maximum tempreture; AR, Annual rainfall; POPD, Population density; MSF, Marginal and small farmers; IRRI, Irrigation intensity; CRII, Cropping intensity; CULT, Cultivators; WORKR, Marginal workers; TWORKR, Total main worker; FCP, Food crop productivity; NFCP, Non-food crop productivity.

indicating that weather variables reduce the crop diversification. Irrigation intensity had a negative impact on crop diversification due to poor canal management and lack of perennial rivers, illustrating that increasing irrigation intensity reduces crop diversification.

Higher cropping intensity is usually accompanied by increased irrigation intensity. The present study reveals that cropping intensity influences crop diversification index positively, but irrigation intensity negatively. Crop diversification is positively correlated with cropping intensity but negatively correlated with irrigation intensity, as evidenced by the panel correlation matrix (Table 4). Cropping intensity and irrigation intensity, on the other hand, are positively related. Despite the fact that higher cropping intensity is associated with higher irrigation intensity, crop diversification is found to be higher in districts with lower irrigation intensity. This indicates that higher cropping intensity is restricted to mono-cropping, where irrigation intensity is relatively higher, whereas it is associated with multi-cropping in the rainfed lower hill districts of HP[16]. Table 4 also reveals an interesting finding: a moderate degree of correlation (0.51) exists between irrigation intensity and food crop yield index. So, high-yielding crops which use water intensively are scarcely grown in this region.

Therefore, high food productivity crops and varieties contribute to crop concentration rather than diversification. Similarly, irrigation systems in HP differ depending on how water is distributed to the crops. More lift and khul irrigation promote mono-cropping of cereals and vegetables over minor (lift and flow) irrigation. The marginal and small farmers have a negative effect, increasing crop concentration. Marginal and small farmers are increasing crop specialization due to limited credit availability and limited access to information and communication technology. Crop diversification is heavily influenced by rural population density per kilometre.

Farmers are more likely to diversify their crop portfolio as the population density increases. Crop diversification is therefore expected to be more in districts with a higher rural population density. The rainfall coefficient is negative with regard to the impact of rainfall and minimum temperature on crop diversification. The maximum temperature is positively related to and increases crop diversification. This is because temperatures increase the likelihood of droughts, floods and irregular rainfall. Crop diversification index is positively related to cultivators and total main workers. It also implies that cultivators and other primary workers help increase crop diversification. As the number of cultivators and total main workers increases, so does the availability of labour in agriculture. As a result, more crops are grown and crop diversification increases (Table 3). Panel correlation reveals a positive relationship between cultivator, total main workers and crop diversification index (Table 4).

Sirmaur district is diverse, Kangra and Mandi are highly diversified, but Solan is highly specialized in agriculture in HP. The fixed effects model was chosen based on the results of the Hausman test, which indicated that including spatial fixed effects in panel data models is important for controlling time-invariant, location-specific characteristics that may be correlated with variables. The time-fixed effects are also significant, highlighting the role of farm-level changes in agronomic and cropping practices due to climate change. The population density, percentage of marginal and small farmers, cropping intensity, cultivators, marginal workers and total main workers all play a significant role in crop diversification, implying that crop diversification is led by them. The impact of weather variables reveals that an increase in rainfall and minimum temperature has a significant negative impact on crop diversification, implying that lead crops would be concentrated. Irrigation intensity has a negative impact on crop diversification due

Table 4. Correlation matrix for the panel

Variable	CDI	TMIN	TMAX	AR	POPD	MSF (%)	CRII	IRRI	CULT	WORKR	TWORKR	FCP	NFCP
CDI	1.00												
TMIN	0.01	1.00											
TMAX	0.15	0.40***	1.00										
AR	–0.32***	–0.14	–0.45***	1.00									
POPD	0.15	–0.35***	–0.19	0.02	1.00								
MSF (%)	–0.32***	–0.39***	–0.23**	0.48***	0.52***	1.00							
CRII	0.21	0.05	0.12	–0.12	0.22**	–0.29***	1.00						
IRRI	–0.26**	–0.14	0.04	0.19	0.36***	0.45***	0.32***	1.00					
CULT	0.36***	–0.24**	–0.56***	0.46***	–0.11	0.44***	–0.52***	–0.09	1.00				
WORKR	0.18	–0.33***	–0.53***	0.51***	0.16	0.49***	–0.23**	–0.06	0.83***	1.00			
TWORKR	0.28***	–0.24**	–0.56***	0.55***	–0.08	0.44***	–0.32***	–0.08	0.92***	0.91***	1.00		
FCP	0.22**	–0.18	–0.24**	–0.10	0.05	–0.20	0.11	0.51***	0.16	0.19	0.20	1.00	
NFCP	–0.24**	0.23**	–0.02	–0.05	–0.21	–0.33***	0.13	0.06	–0.04	–0.13	–0.07	0.12	1.00

**Correlation is significant at the 0.05 level (two-tailed). ***Correlation is significant at the 0.01 level (two-tailed).

to poor canal management and a lack of perennial rivers, illustrating that increasing irrigation intensity reduces crop diversification. The study of the relationship between irrigation intensity and diversification reveals that crop diversification depends on the khul and lift irrigation systems that lift water from the river. The water resources are overexploited in the study region because a surface ground irrigation method was used. So there is need of proper management of surface irrigation with the crop calendar to reduce the stress on groundwater. The findings of the present study necessitate the proper monitoring of irrigation for sustainable agriculture.

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