ICRISAT AND WFP: India Working Paper

Effect of Climate Change on Food Stability in the Context of Food Security in India

ICRISAT and WFP: India Working Paper

Effect of Climate Change on Food Stability in the Context of Food Security in India

KEY PERSONNEL

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS (ICRISAT)

Shalander Kumar, Deputy Global Research Program Director: Enabling Systems Transformation Program

Soumitra Pramanik, Associate Scientist - Economics

Elias Khan, Senior Scientific Officer - Agricultural Economics

S. Nedumaran, Principal Scientist - Economics

Abhishek Das, Scientist- Agricultural Economics

WORLD FOOD PROGRAMME (WFP) INDIA COUNTRY OFFICE

Pradnya Paithankar, Head, Climate and Resilient Food Systems

Abhay Kumar, Head, RAM & Evaluation Unit

Ayushi Jain, Senior Programme Associate, RAM & Evaluation Unit

Vijay Avinandan, M&E Officer, RAM & Evaluation Unit

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial uses is authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission. Applications for such permission should be addressed to the Communications Division at WFP.

© 2023 World Food Programme

Cover photo courtesy: pixabay.com

DISCLAIMER

The opinions expressed in this report are those of the research team, and do not necessarily reflect those of the World Food Programme or ICRISAT. Responsibility for the opinions expressed in this report rests solely with the authors. Publication of this document does not imply endorsement by WFP or ICRISAT of the opinions expressed. The boundaries and names shown, and the designations used on these maps do not imply official endorsement or acceptance by the United Nations. The shape files of all the maps used in this report were sourced from the public domain.

Table of Contents

Image courtesy: pixabay.com

Image courtesy: pixabay.com

Introduction

Climate change is a global threat adversely impacting all sectors of the economy and livelihoods (Nema et al., 2012). Global climate change is a change in the long-term weather patterns that characterize the regions of the world. Scientists state unequivocally that the earth is warming. Natural climate variability alone cannot explain this trend. Human activities, especially the burning of coal and oil, are considered to have warmed the earth by dramatically increasing the concentrations of heat-trapping gases in the atmosphere (Vijayavenkataraman et al. 2012). However, the human activity in all the sectors of the economy is contributing to global warming, **after the fossil fuels, food system is the next big contributor to greenhouse gas (GHG) emission- a third of global anthropogenic GHG emissions** (Crippa et al, 2021). The global warming and climate change resulting in extreme weather events and increased climatic variability and have enormous adverse impacts on multiple sectors including agricultural and food production, food and nutrition security and the livelihoods especially in the less developed regions and countries. It is becoming a major global challenge that has far-reaching multi-faceted impacts on all aspects of human life, including food security (Sanober, 2023). India, which is one of the largest agricultural producers in the world, is highly vulnerable to changing climate especially its food production systems. Several studies have assessed and established a relationship between gradual climate change and crop yields (e.g., Aggarwal, 2008; Praveen & Sharma, 2020; Guiteras, 2009; Kumar et al., 2011; Kumar et al., 2004; Mall et al., 2006). Therefore, for the country, which is home to more than 1.3 billion people, ensuring food security for its growing population under the changing climate is a major challenge and a daunting talk for the policy makers. **Food security refers to the availability of food and people's access to it, with the assurance that this access will not diminish in the future.** In other words, food security is a physical, environmental, economic, and social issue. Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (Shaw, 2007). Sufficient food refers to both the quantity and quality required for good health. In general, the food security is the combinations of four dimensions named as physical availability of food (availability), economic and physical access to food (accessibility), food utilization (utilization) and Stability of the other three dimensions over time and food security objectives to be achieved when all four dimensions must be fulfilled simultaneously at all levels from national to regional to household level. The impacts of climate change on stability of food production in India are likely to have significant and far-reaching consequences. The country, which is already facing high level of malnutrition, is now being threatened by the adverse effects of climate change on its food production systems, in terms of reduced crop yields, soil degradation, and increased vulnerability to pests and diseases. These impacts are likely to cause **significant challenges to food production stability, leading to food scarcity, increased food prices, and further food insecurity, particularly for the most vulnerable populations** (Godde et al., 2021). In addition to rising temperatures, changes in precipitation patterns have significant impact on food production in India. Unpredictable rainfall, droughts, and floods are all affecting the availability of water for irrigation and crops. Droughts are particularly damaging to food production in India, as they cause crop failures and reduce yields, leading to food scarcity and food insecurity (Arora 2019; Datta et al., 2022). On the other hand, floods can also have a major impact causing damage to crop, disrupt transportation and food supply chains, and increase the risk of waterborne diseases, all of which can further exacerbate the challenges faced by farm and food systems in India. The stability dimension of food security is a critical aspect of food security policy of the country. **A higher risk of instability of production due climate change may result in high price volatility not only due to short supply but also the changing market perception.** Considering the significance of all these aspects, the present research concentrates on the effect of climate change and variability on the fourth dimension of food security, i.e., stability. Food stability is when a population, household, or individual has access to food at all times and does not risk losing access as a consequence of cyclical events, such as the dry season. When some lacks food stability, they are likely to have malnutrition, a lack of essential nutrients. **There have been a wide range of studies worldwide to find out the impacts of climate change on food security and its various dimensions.** Several of them conclude that the impacts are different for different dimensions of food security. An exhaustive review on the impacts of climate change on food security and its various dimensions by Radin Firdaus et al., 2019- a multi-disciplinary team of researchers from several countries provides an overview of how these changes have affected each dimension, such as availability, accessibility, utilization, and stability. Climatic changes have negative impacts on Food Security and Nutrition (FSN), particularly in poorer populations in situations of social inequality. The main impacts of climate changes on FSN are related to access, production, nutritional quality, and volatility of food prices (Alpino et al., 2022**).** However, there is hardly any evidence available on the impact of climate change and variability on food stability at the country level, which is critical for designing suitable food security policies. Therefore, we attempt to **fill this evidence gap by undertaking a study to evaluate the impact of climate change on food stability status at districts level in India for various major food crops.**


Image courtesy: pixabay.com

Data and Methodology

2.1 DESCRIPTION OF DATA

The present study has used two types of data sets, crop data and climate related data. In case of crop data, the study used all India basis district wise crop area, production, and yield data for major food crops. The data were extracted from ICRISAT online district level data (DLD)[1] base which is available online for public use which provide information for Indian agriculture and allied sectors. The DLD is a comprehensive one-stop shop for data on rural sector that enables testing of key research hypotheses, identification of relevant districts/regions for technology dissemination, promoting rural pro-poor programs/development initiatives and identification of relevant representative districts for micro level assessment. The database consists of two types of data; apportioned database and unapportion database which consider current district boundaries. In the present analysis district wise unapportion database have been considered and it covers **571 districts with 20 states as per 2015 state and district boundaries.** As per the available data, the latest **twenty years data from 1998 to 2017 have been used for the study.** The study focused on major food crops with substantial area coverage and used a minimum area criterion to select various crops and the number of districts considered for each crop. Table-1 provides information on the minimum area (in hectares) in the stipulated period considered for selection of various crops and the number of districts chosen for the purpose. As indicated in table 1, for rice and wheat those districts were included in the analysis which have at least an area of 5000 hectares or more under each of the crops, as a result 343 and 281 districts were considered for rice and wheat, respectively. Similarly, for the crops such as maize, pearl millet, and groundnut we included the districts in our analysis which has a cropped area of at least 2500, 2000, and 2000 hectares respectively, giving 183, 99, and 125 districts for maize, pearl millet, and groundnut. For the other crops like sorghum-kharif, chickpea, pigeon pea, and rapeseed & mustard the districts having at least an area of 2000 hectares under the crop as result 64, 136, 119, and 161 districts, respectively were considered. Since the crops like sorghum-rabi, finger millet, sesame, soybean have relatively smaller cropped area, we considered the districts which have cropped area ranging from 1000 to 1500 hectares, considering 38, 39, 94, and 61 districts respectively. **As a result, the top 3/4th of the districts under each crop were included in the analysis and districts with insignificant levels of production were ignored so that meaningful conclusions can be drawn.**

***Table 1**: Crop wise district selection criteria and no of districts selected for analysis*

Crop group	Crop name	Minimum Area (Ha)	N.o of Districts
Major cereals	Rice	5000	343
	Wheat	5000	281
	Maize	2500	183
Millets	Pearl millet	2000	99
	Finger millet	1000	39
	Sorghum-kharif	2000	64
	Sorghum-rabi	1000	38
Pulses and legumes	Chickpea	2000	136
	Pigeon pea	2000	119
	Soybean	1500	61
Oilseeds	Rapeseed & mustard	1500	161
	Groundnut	2000	125
	Sesame	1000	94

For constructing the climate variability index, the study used of several climate related variables (Table 2) for 30 years from the period of 1990 to 2020 at district level India. All the climate data were sourced from the

1 The data available from http://data.icrisat.org/dld/

India Meteorological Department (IMD), which were used to construct a district level **Climate Variability Index (CVI)** for the whole country. The details of the method have been provided in the next section.

2.2 METHODOLOGY

The methodology section for the present analysis has been divided into two parts: firstly measuring, status and distribution of instability index and secondly, examining the impact of climate variability on instability of food crops area, production, and yield.

To measure the stability of area, production and yield of different food crops we estimated the instability index for each crop and each district as the instability is considered as the indirect method of measuring stability and more instability indicate less stability as per the definition. **Agricultural instability especially for the food crops has been an important issue that has garnered considerable attention in the agricultural sector.** Measuring agricultural instability is an essential aspect of assessing and managing risks associated with agricultural and food production. Various methods have been proposed to measure agricultural instability, including the Coefficient of Variation (CV), dispersion, Cuddy Della Valle Index (CDVI), and Coppock Instability index. The coefficient of variation is a commonly used measure of agricultural instability. However, it is not suitable for trended data since it fails to account for the correlation between the data series and trend measures. Therefore, a more comprehensive measure of instability is required to address this concern. The general measure of instability is based on the definition of the coefficient of multiple determination, combined with the simple coefficient of variation and is adjusted according to the degrees of freedom involved in a specific regression model. Given that the present study is based on long-term time series data, there is a need to use a suitable method for estimating the instability index which also considers the time series nature data. Thus, this **study uses the Cuddy Della Valle Index method to measure the instability of crop area, production, and yields**. The Cuddy Della Valle Index first de-trends the given series and gives a clear direction about the instability. The use of coefficient of variation as a measure to show the instability in any time series data has some limitations. If the time series data exhibits any trend, the variation measured by CV can be overestimated. For instance, the region which has growing production at a constant rate will score high in instability of production if CV is applied for measuring instability. In contrast, the Cuddy-Della Valle index attempts to de-trend the CV by using the coefficient of determination ($\bar{R}^2$). Thus, it is considered a better measure to capture instability in agricultural production. A low value of this index indicates low instability in farm production, and vice versa. CDVI was originally developed by Cuddy and Valle (1978) for measuring the instability in time series data that is characterized by trend. Therefore, a more comprehensive measure of instability, such as the Cuddy Della Valle Index, was used in this study which can address this concern.

The estimation equation to estimate of CDVI of instability is as follows:

$$\text{CDVI} = CV \times \sqrt{1 - \bar{R}^2} \qquad (1)$$

Where CV is the coefficient of variation in percent, and $\bar{R}^2$ is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom. The ranges of CDVI (Figure 1) are given as follows, index value between 0 to 15 consider as low instability, medium instability considered when the index value ranges between 15 to 30 and if the value is above than 30 then it is documented as high instability.

To estimate the **district wise Composite Instability Index (CII) for area, production and yield** we have followed the below mentioned steps:

a. Firstly, estimated average area proportion of individual crop in total crop area (considering major food crops for that district) for each district which represents as weight of importance for each crop in that district.

b. Secondly, multiplied actual individual crop instability index of area, production and yield with the corresponding area proportion for each district.

c. Finally, summing up weighted index value for area, production and yield for each district which represent the district wise composite instability index value for area, production, and yield.

Figure 1*: Crop Instability index categories based on CDVI values*

The process has been described in equation-2 below;

$$CII_{(a,p,y)_j} = \sum_{\substack{i=1 \\ j=1}}^{\substack{i=n \\ j=n}} \left(\frac{ICA_{ij}}{TCA_j} \right) X \left(CDVI_{(a,p,y)_{ij}} \right) \quad (2)$$

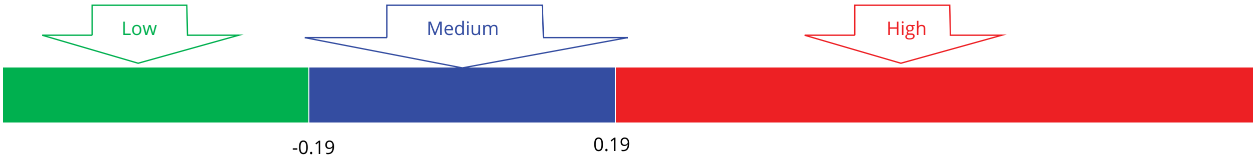
Where, CII is the composite crop instability, a, p, y indicates area, production and yield, ICA stands for individual crop area, TCA is total crop area, CDVI indicate Cuddy Della Valle Index of instability and i, j represents specific crop and particular district respectively.

The climate variability index is a composite index constructed using key climate variables (Table 2); rainfall, temperature and disaster weather events and includes 26 climate indicators derived from the basic climate data on rainfall, temperature, hailstorms, drought, flood etc. then the final value estimated and multiplied with respective weight and summed up (the detailed of estimation of final value of each indicator describe in Table 2). To decide the realistic weight of each of the climate indicator the ICRISAT team has depended on several **stakeholders' consultations conducted during the past couple of years as part of multiple projects on climate vulnerability assessments and climate smart agriculture scaling.** The research team also had several internal interactions to finalize these weights. The relative importance of the different climate variables in relation to different ago-climatic zones (ACZ) in India was also considered while finalizing weights. All the districts of India except Islands have been divided in 12 zones and as per the significance of different climate indicators for the respective farming/cropping systems, the weight have been decided. Finally, the index value of climate variability was estimated for each district and categorized as low, medium and high based on the value of the index as presented in Figure 2.

***Table 2**: Basic climatic variables and related indicators included in the climate variability index (CVI)*

Broad climate variables	Indicators
Rainfall (15 indicators)	CV of Annual rainfall (%)
	CV of Monsoon rainfall (%)
	CV of June rainfall (%)
	CV of July rainfall (%)
	Number of annual rainy days
	Number of monsoon rainy days
	Heavy rainfall days
	Very heavy rainfall days
	Number of times more than 14 days of dry spell in monsoon (no/time slice)
	Number of times more than 14 days of wet spell in monsoon (no/time slice)
	Number of times more than 10 days of dry spell in monsoon (no/time slice)
	Number of times more than 10 days of wet spell in monsoon (no/time slice)
	Drought proneness
	Flood proneness
	Average highest rainfall in a single day as % to annual normal
Temperature (8 indicators)	Monsoon Maximum Temperature
	Monsoon Minimum Temperature
	Heat wave occurrences (days)
	Cold wave occurrences (days)
	Severe Heat wave occurrences (days)
	Severe Cold wave occurrences (days)
	Number of times more than 3 days of temperature >=35 during monsoon
	Terminal heat stress (temperature rise in February and March)
Disaster weather events (3 indicators)	Floods, Flash floods, Cloud burst, Landslide
	Cyclonic storms
	Hailstorms

***Figure 2**: Climate variability index grouping criteria*



To represent the status of crop wise and overall area, production and yield instability, the present study deployed tabular method and use spatial tools to represent exact situation of instability for each district across crops and overall index for different attributes.

In the next part of the methodology section, we have provided the details about how the climate variability index is related to the instability index. To measure the impact of climate variability on instability of crops, initially the impact matrix was constructed as presented in Figure 3. The matrix presents nine different attributes, and those were grouped into three different categories: **i) no impact, ii) low to medium impact and iii) high impact due to climate variability.**

The present study examined the effect of climate variability on instability of area, production and yield of major food crops in various ways. Firstly, we have summaries of the status across crops and overall, for various attributes presented in a table. Then spatial maps were generated to effectively illustrate the effect of climatic variability on area, production, and yield instability of different major food crops for each district.

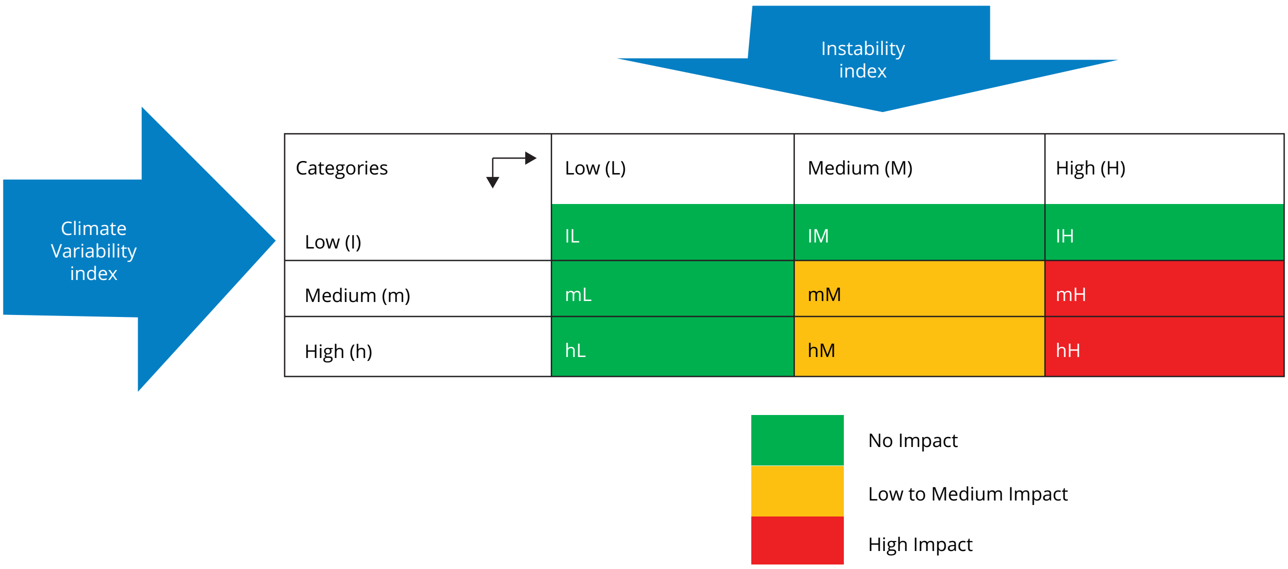
Further a simple linear regression method was used to measure the absolute effect using the following equation;

$$CDVI = \alpha + \beta CVI + u \qquad (3)$$

Where, *CDVI is the absolute value of Cuddy Della Valle Index of instability, CVI represent absolute value of climate variability index, a and β are the regression coefficient and u represent the error term. The regressions were performed for each crop considering different attributes separately.*

Finally, we have used a chi-square test of independence that checks whether two variables are likely to be related or not and represent relative effect. The test gives us a way to decide if our idea is plausible or not. The frequency of each category for one nominal variable is compared across the categories of the second nominal variable. The data can be displayed in a contingency table where each row represents a category for one variable and each column represents a category for the other variable. Also, the test compares the observed frequencies to the frequencies you would expect if the two variables are unrelated. When the variables are unrelated, the observed and expected frequencies will be similar.

***Figure 3**: Matrix of relationship between climate variability and crop area, production, and yield instability*



Measuring Crop Wise Area, Production, and Yield Instability Across Districts

This section provides a detailed account of the measurement of crop-wise area, production, and yield instability status across different districts of India. Thirteen major food crops have been included in the analysis. The instability index has been estimated for each crop and, also a composite index for each district considering all the major crops. The major cereals including millets, pulses and legumes, and oilseeds have been grouped and analyzed. The instability analysis has been conducted using two methods: cross-tabulation and spatial mapping. The latter method was used to depict the exact status of each district for the area, production, and yield instability across different crops. The findings of the instability analysis have been presented in detail in the subsequent sections.

3.1. STATUS OF COMPOSITE CROP INSTABILITY AT DISTRICT LEVEL

Table 3 presents an analysis of the crop-wise area, production, and yield instability status across 463 districts in India using a composite instability index which considered all the major food crops and the corresponding districts which fulfill the criteria of selection as stated above section of the paper. The results reveal that **93% of the districts fall under low to medium instability in terms of area, whereas 48% of the districts exhibit high instability in production, with only 17% categorized as low instability.** Many of the districts (44%) display medium instability in yield, followed by low (32%) and high (24%) instability. The spatial map created based on the instability analysis provides valuable insights into the geographic distribution of instability across the country. The map (Figure 4) highlights that most of the **districts in the eastern and northeastern parts of India have low instability in terms of area, while a majority of the medium unstable districts are located in the western and southwestern parts of the country.** The highly unstable districts are scattered across the country without any significant pattern. In terms of production instability, the western and southwestern regions of India have a high number of unstable districts, while the eastern and northeastern regions have mostly medium to low levels of instability. The northern, middle, and some southern parts of India exhibit high levels of yield instability, while the eastern, northeastern, and some parts of the northern regions exhibit low levels of instability. The remaining districts are categorized as medium instability. Overall, this section provides a comprehensive understanding of the geographic distribution of instability across the country, and the information obtained can help mitigate the negative impact of instability on the agricultural sector. Further **research can be conducted to explore the factors contributing to the instability and to develop appropriate strategies to address the issue.**

***Table 3**: Area, production and yield instability status of composite crop index (% of districts, N=463)*

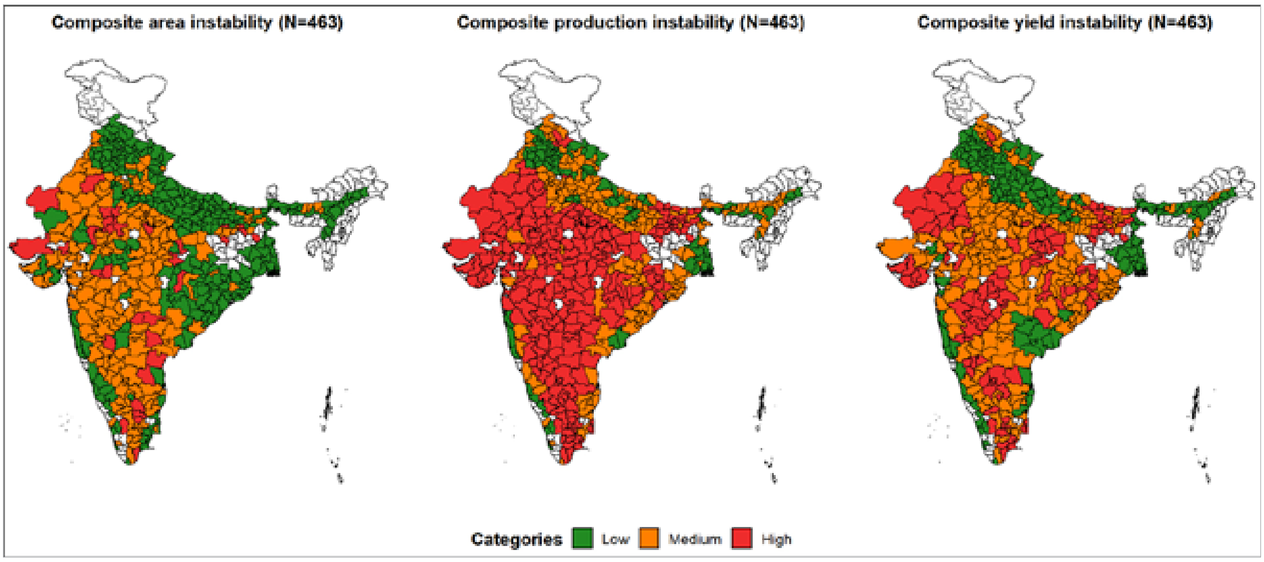
Instability category	Area	Production	Yield
Low	55.94	17.06	32.40
Medium	36.93	34.77	44.06
High	7.13	48.16	23.54

3.2. STATUS OF CROP SPECIFIC INSTABILITY

3.2.1. Area, Production and Yield Instability Status of Rice, Wheat, and Maize

The distribution of acreage, production, and yield instability status for the major cereals among districts has been shown in Table 4 and Figure 5 to Figure 7. Rice has the lowest percentage of districts with a high area instability rating (6%), while maize has the greatest percentage (22%). Rice has the lowest level of production instability (4%), whereas maize has the highest percentage (65%) of districts with a high instability classification. When it comes to districts with low yield instability, wheat has the highest percentage (47%), while maize has the lowest (11%). As depicted in the Table 4 and Figures 5 to 7, maize is the cereal crop with the highest level of instability in terms of both acreage and production. This might be explained by the fact that maize

***Figure 4**: Spatial analysis of area, production and yield instability of composite crop index*



is frequently farmed in the regions with diverse weather patterns and levels of soil fertility, rendering it prone to crop failure. Contrarily, **rice looks to be the highest level of stability, ranking low in all three categories.** This might be because rice is frequently farmed in regions with controlled irrigation systems, which guarantee steady crop growth and productivity.

Therefore, these findings underline the importance of understanding the intensity of cereal crop instability in various districts to guide farmers in making well-informed decisions about crop management and selection. The implementation of policies and initiatives that support the resilience and stability of agricultural production systems can be aided by this information for policymakers.

***Table 4**: Distribution of area, production, and yield instability status of major cereal crops across district (% districts)*

Type of instability	Categories	Rice (N = 338)	Wheat (N = 273)	Maize (N = 183)
Area	Low	67	58	40
	Medium	27	30	38
	High	6	11	22
Production	Low	27	27	4
	Medium	43	39	31
	High	30	34	65
Yield	Low	51	47	11
	Medium	27	43	55
	High	22	11	34

***Figure 5**: Spatial analysis of area, production and yield instability of rice across districts in India*

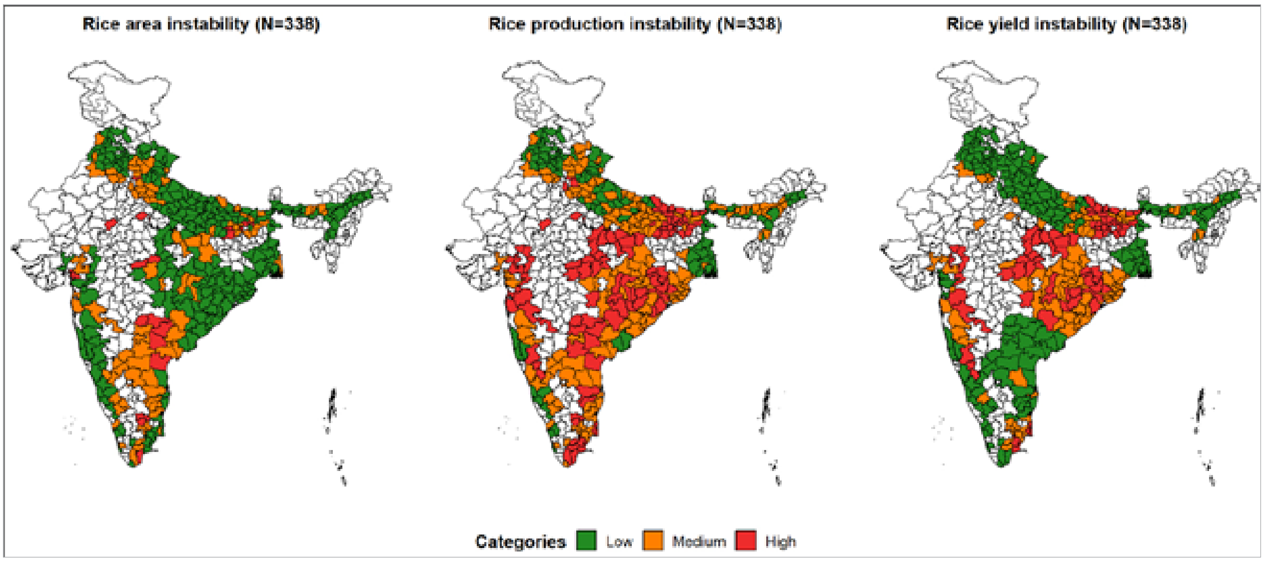


***Figure 6**: Spatial analysis of area, production, and yield instability of wheat across districts in India*

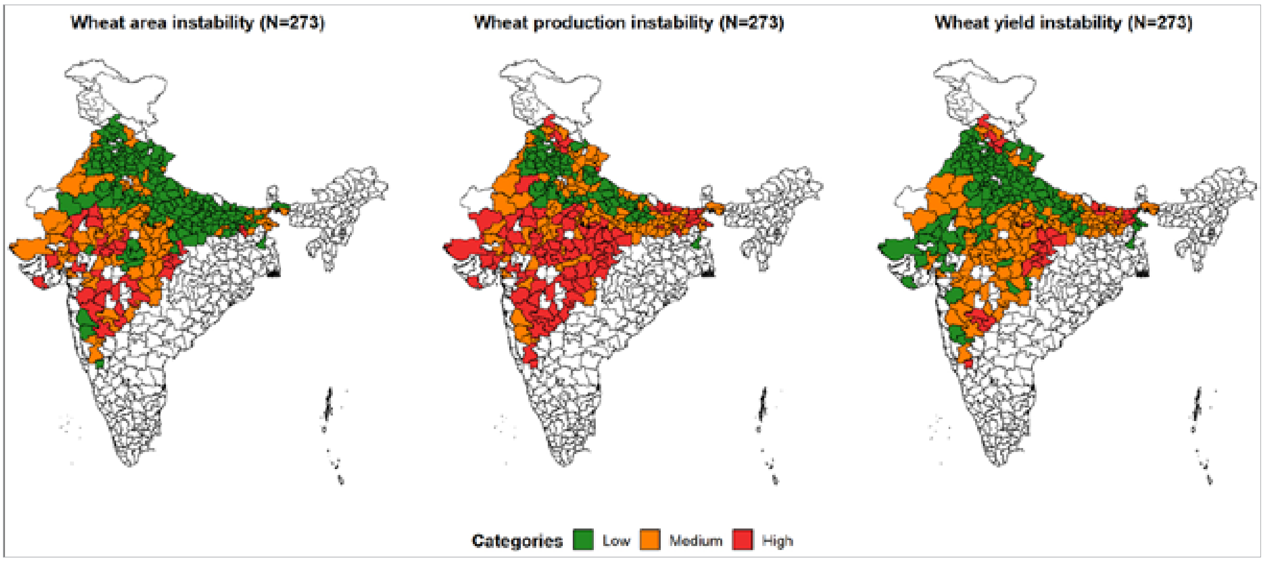
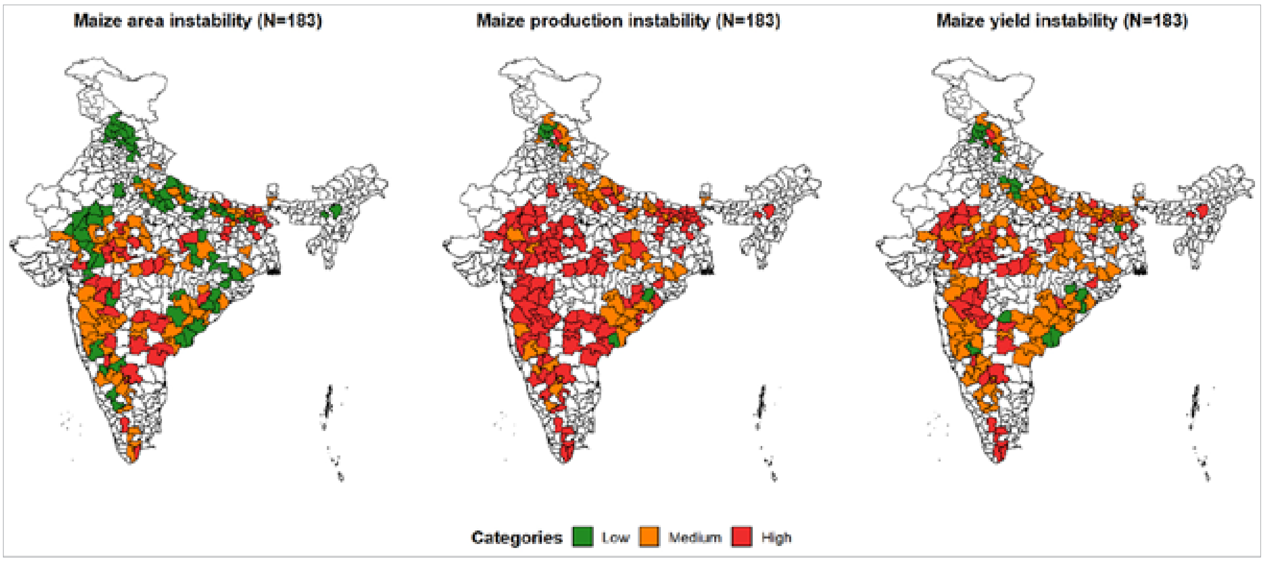


***Figure 7**: Spatial analysis of area, production, and yield instability of maize across districts in India*



3.2.2. Area, production and yield instability status of Millets - Pearl millets, Finger millets, Sorghum

Table 5 and Figure 8 to Figure 11 provides an analysis of the instability of area, production, and yield for four major millets across districts in India. Besides pearl millet, and finger millet, the sorghum is of two types - kharif and rabi.

In terms of area instability, Table 5 shows that pearl millet has the highest proportion of districts with medium instability (41%), while finger millet has the highest proportion of districts with low instability (39%). Sorghum-rabi has the highest proportion of districts with high area instability (32%), which is a cause for concern as it indicates that the crop is not being cultivated in a stable manner in these areas.

Regarding production instability, most districts for these rainfed crops have high levels of production instability, with finger millet having the highest proportion (66%) and sorghum-kharif having the lowest (71%). Only a few districts have low production instability levels, and sorghum-rabi has no districts with low production instability levels. This result suggests that there is a **need to better understand the drivers of the instability and focus on improving the stability of millet production in these districts through appropriate farming practices and policies.**

Regarding yield instability, the analysis shows that for the sorghum-kharif half of the districts have high and other half medium instability and none fall in low instability category. The pearl millet has the highest proportion of districts with medium yield instability (48%). Finger millet has the highest proportion of districts with low yield instability (26%), which is a positive sign for the reliability of the crop in these areas. Sorghum-rabi yield instability is also either high or medium in most of the districts which is a cause for concern and requires attention from policymakers and farmers in these areas. **Though these millets are considered resilient crops, in practice their yields and production have high instability.** Overall, the analysis highlights the need for improving the stability of area, production, and yield for major millets across different districts. The information presented could be useful for policymakers and farmers in developing strategies to improve the cultivation, production, and reliability of millets in different areas. For example, policymakers could focus on developing programs to incentivize the adoption of sustainable farming practices that can increase the stability of millet cultivation and production, while farmers could adopt better moisture conservation techniques and crop rotation to increase yield stability.

***Table 5**: Distribution of area, production, and yield instability of major millets across district (% districts)*

Type of instability	Categories	Pearl millet (N=99)	Finger millet (N=38)	Sorghum-kharif (N=62)	Sorghum-rabi (N=38)
Area	Low	37	39	27	24
	Medium	41	42	55	45
	High	21	18	18	32
Production	Low	5	8	2	0
	Medium	36	26	27	24
	High	59	66	71	76
Yield	Low	18	26	0	5
	Medium	48	53	50	61
	High	33	21	50	34

Figure 8: Spatial analysis of area, production, and yield instability of pearl millet across districts in India

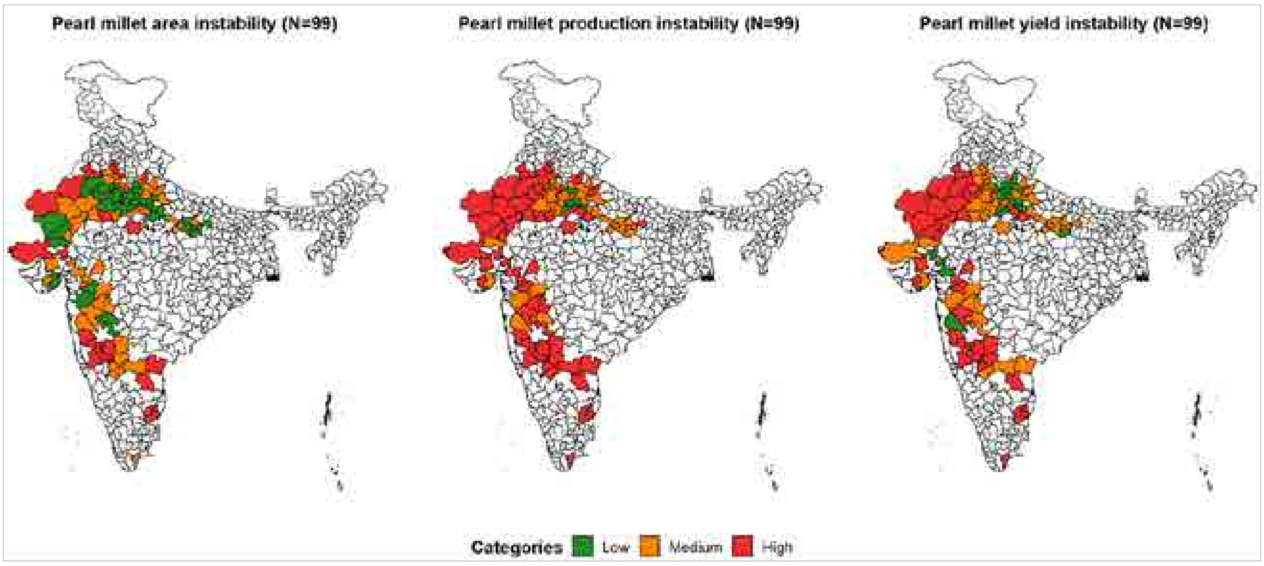


Figure 9: Spatial analysis of area, production, and yield instability of finger millet across districts in India

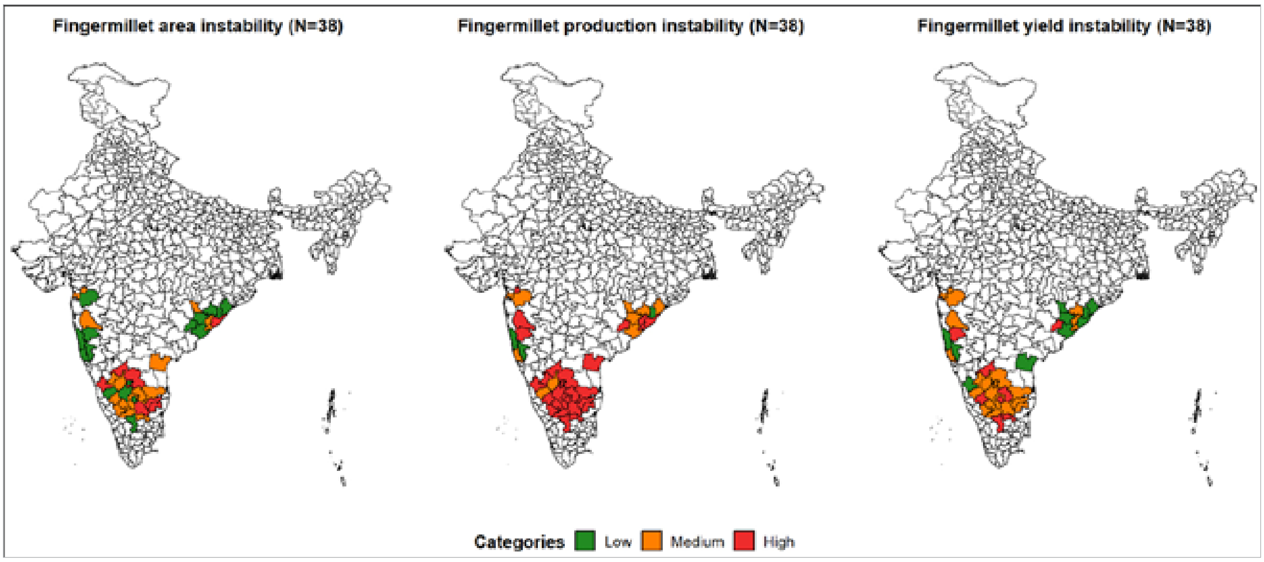


Figure 10: Spatial analysis of area, production, and yield instability of sorghum-kharif across districts in India

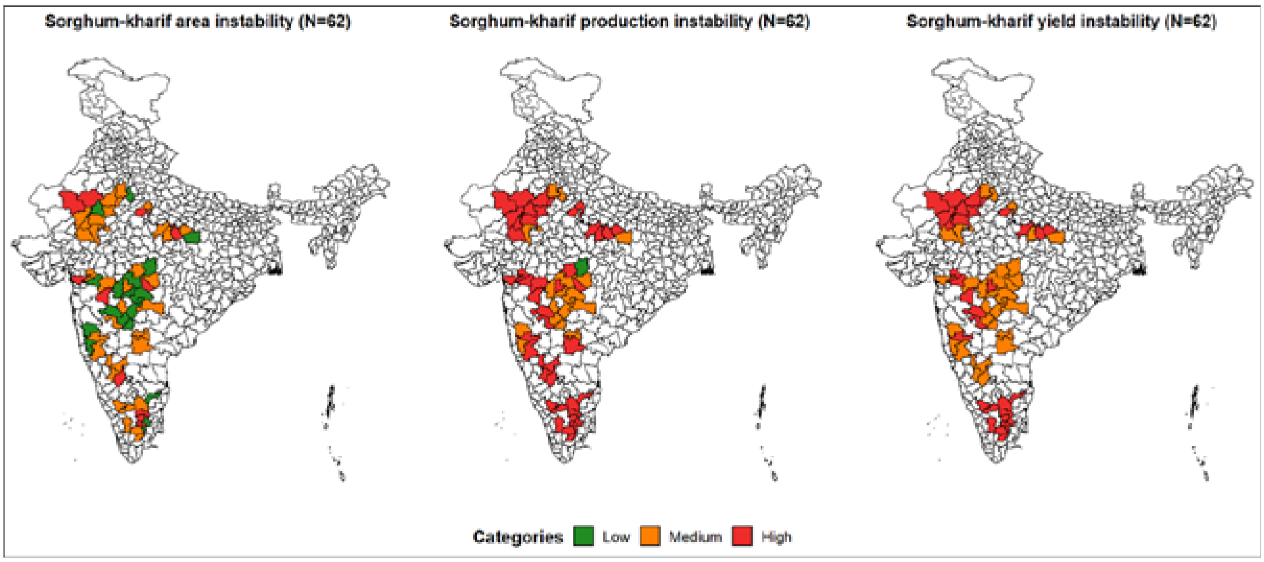
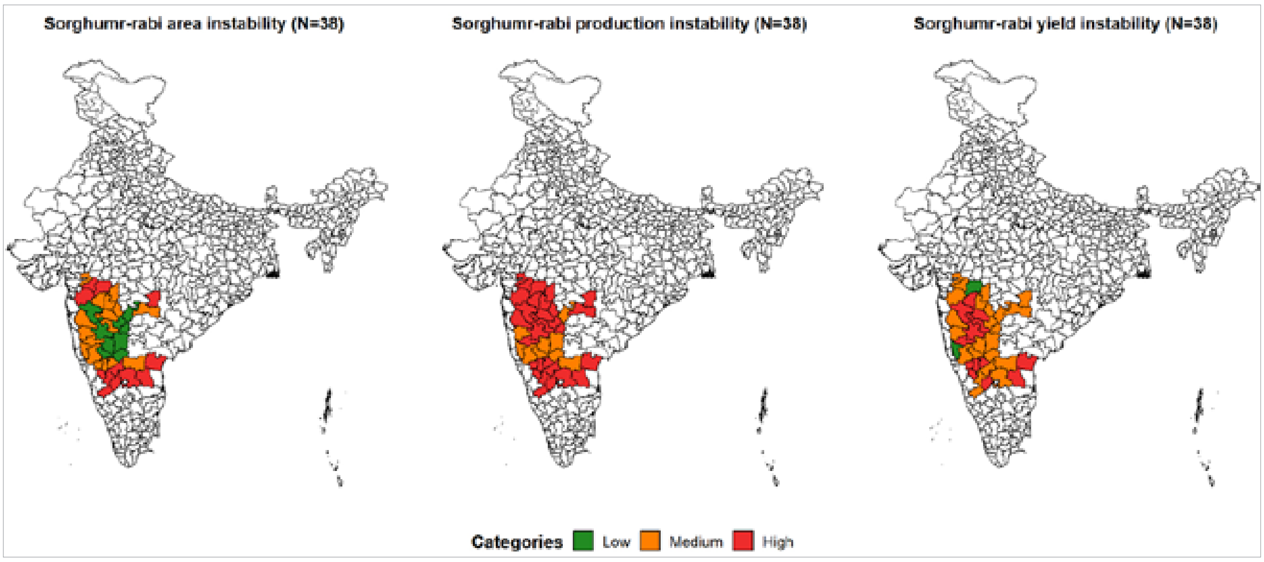


Figure 11: Spatial analysis of area, production, and yield instability of sorghum-rabi across districts in India



3.2.3. Area, production, and yield instability status of major legume crops- Chickpea, Pigeon pea, Soybean

This section provides an analysis of the instability of area, production, and yield for three major legumes across districts, namely chickpea, pigeon pea, and soybean (Table 6, Figure 12 to Figure 14). In terms of area instability, the pigeon pea has the highest proportion of districts with medium instability (45%), followed closely by chickpea (38%). **Chickpea has the highest proportion of districts with high area instability (46%)** followed by soybean (32%). This indicates that the cultivation of chickpea and soybean have high risk and need suitable strategies to improve resilience.

Regarding production instability, the analysis shows that all three legumes have high levels of production instability, with soybean having highest proportion of districts with high instability (83%), followed by chickpea (78%) and pigeon pea (76%) This highlights the **need for appropriate polices for improving the stability of legume production which is critical for ensuring protein availability in the country where majority of the people are vegetarian.**

Further the analysis shows that the yield instability was high in majority of the districts for soybean (63%) and pigeon pea (60%). These major legume crops are important not only as source of protein and soil fertility but also market oriented crops of the rainfed regions. The high yield instability is a cause of concern and needs to be addressed through appropriate policies.

Overall, the analysis highlights the need for improving the stability of area, production, and yield for major legumes across different districts. Policymakers and farmers can use this information to develop strategies to improve the cultivation, production, and reliability of legumes in different areas. For example, policymakers could focus on effective drought adaptation strategies and quality seeds, while farmers could adopt better pest management practices to increase yield stability.

Table 6: Distribution of area, production and yield instability of pulses and legumes across district (% of districts)

Type of instability	Categories	Chickpea (N=134)	Pigeon pea (N=119)	Soybean (N=59)
Area	Low	16	30	31
	Medium	38	45	37
	High	46	24	32
Production	Low	0	3	0
	Medium	22	20	17
	High	78	76	83
Yield	Low	5	6	0
	Medium	65	34	37
	High	30	60	63

***Figure 12**: Spatial analysis of area, production, and yield instability of chickpea across districts in India*

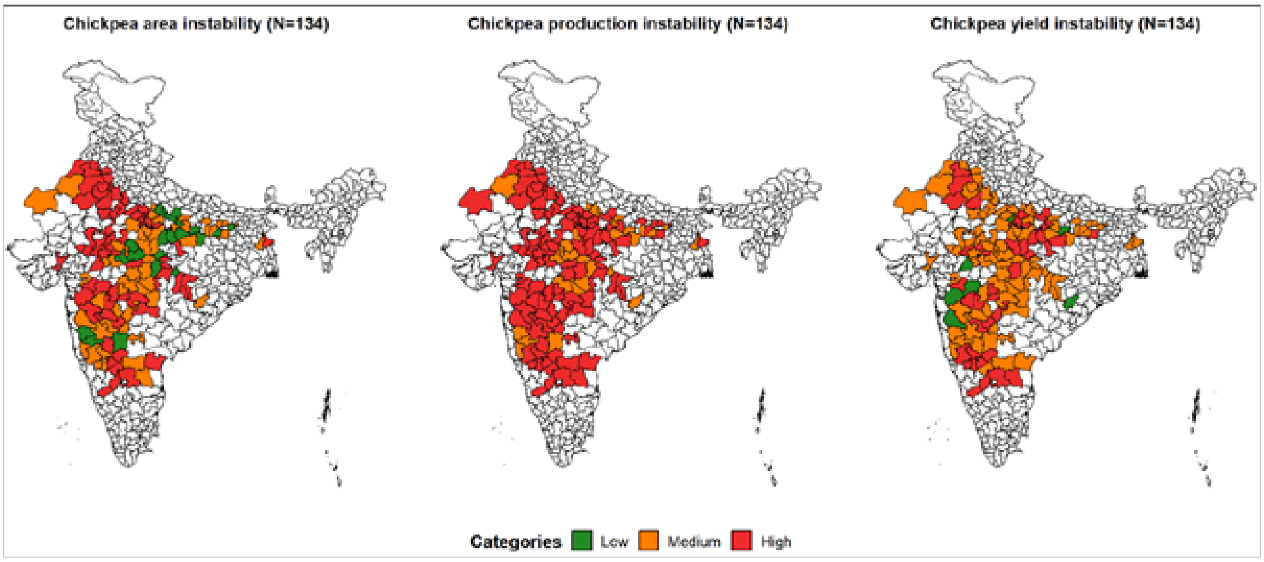


***Figure 13**: Spatial analysis of area, production, and yield instability of pigeon pea across districts in India*

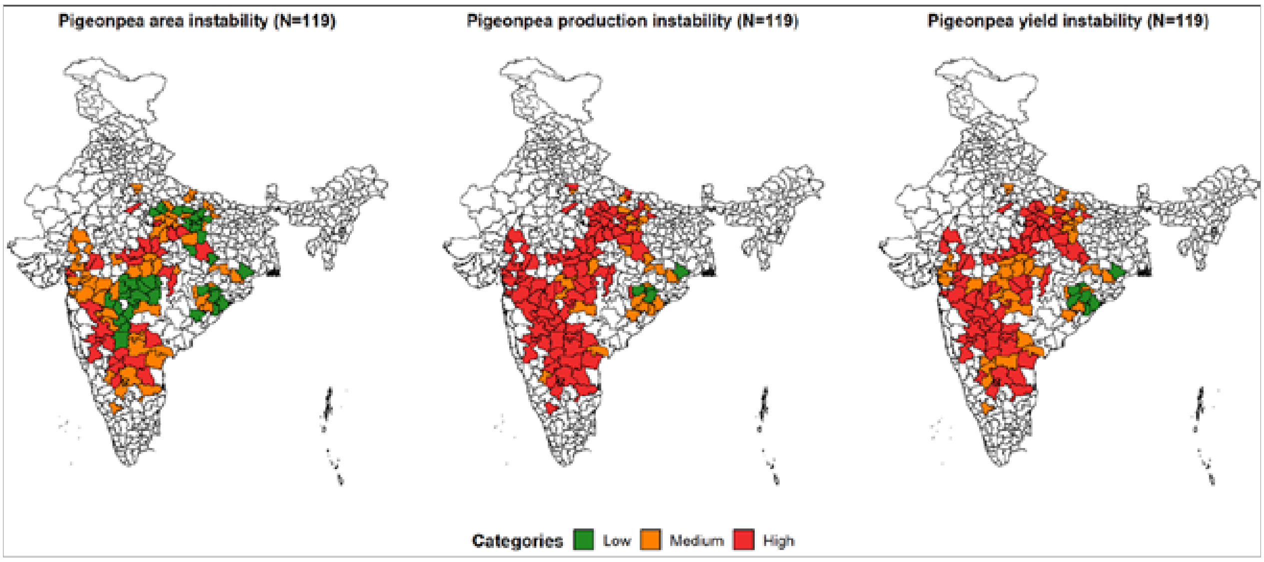
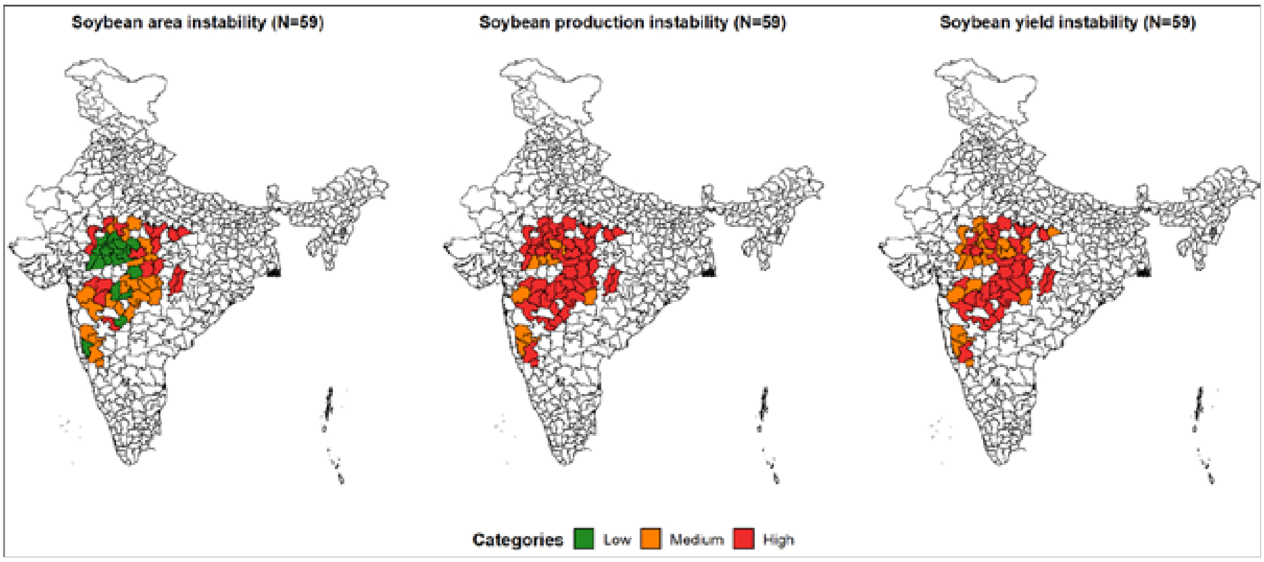


***Figure 14**: Spatial analysis of area, production, and yield instability of soybean across districts in India*



3.2.4. Area, production, and yield instability status of major oilseed crops- Rapeseed & mustard, Sesame, Groundnut

Analysis of the instability of three major oilseed crops, namely rapeseed & mustard, sesame, and groundnut, across different districts in terms of area, production, and yield instability has been presented Table 7 and Figure 15 to Figure 17.

It was revealed that **sesame crop area, production and yield was highly instable in majority of the sesame producing regions** (Table 7).

The groundnut was the next oilseed crop which faces instability of crop area, production, and yield. Majority of the groundnut producing districts (54-59%) had medium level of instability. Rapeseed & mustard has the highest proportion of districts with low yield instability, at 30%. However more than 90% of the mustard producing districts had medium to high level instability in its output production. **India has a huge deficit in edible oil production as compared to its domestic demand and aspires to reduce its oil import bill.**

In such a situation this high level of instability in the oilseed production should be a cause of concern. There is a need to understand the drivers of instability and adopt appropriate farming practices and policies to improve the stability of oilseed production in the identified districts.

***Table 7**: Distribution of area instability of oilseeds across district (% districts)*

Type of instability	Categories	Rapeseed & mustard (N=161)	Sesamum (N=94)	Groundnut (N=124)
Area	Low	32	6	22
	Medium	40	30	56
	High	27	64	22
Production	Low	4	1	2
	Medium	48	12	39
	High	47	87	59
Yield	Low	30	10	20
	Medium	61	30	54
	High	9	61	26

***Figure 15**: Spatial analysis of area, production, and yield instability of Rapeseed & mustard across districts in India*

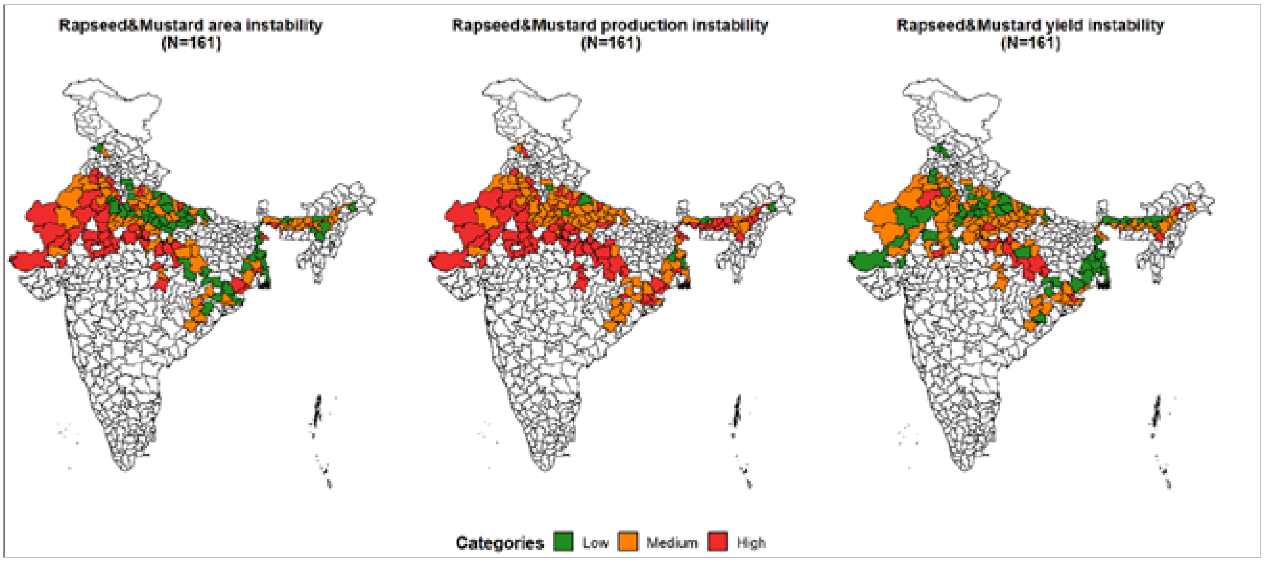


***Figure 16**: Spatial analysis of area, production, and yield instability of Sesamum across districts in India*

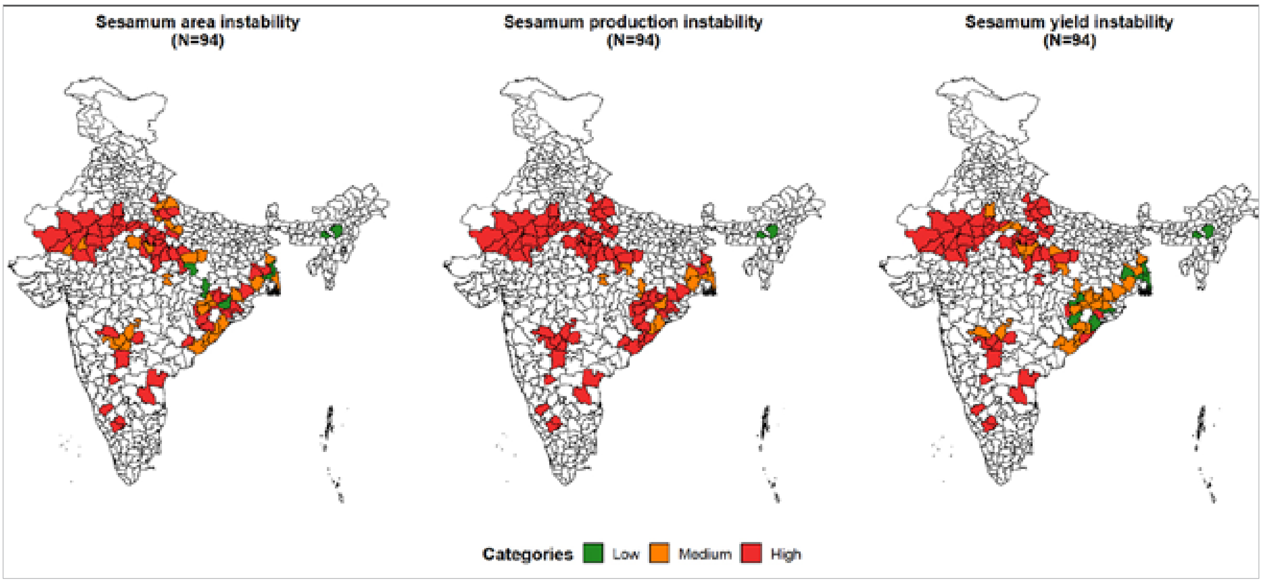


***Figure 17**: Spatial analysis of area, production, and yield instability of Groundnut across districts in India*

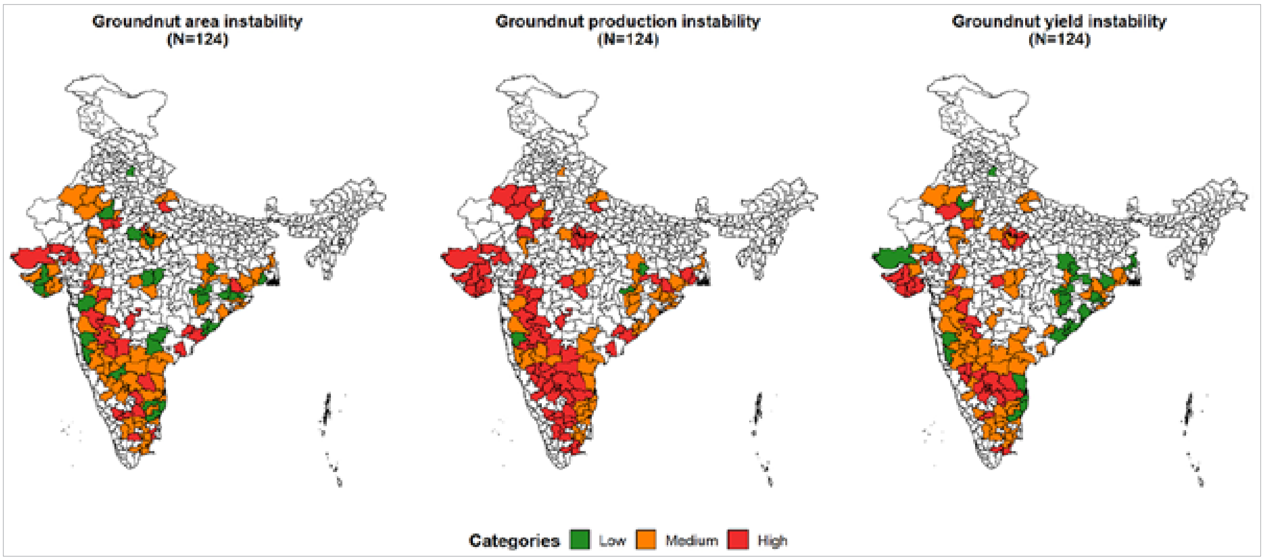


Image courtesy: pixabay.com

Effect of Climate Variability on Composite Instability of Major Food Crops

The first step was to understand the level of instability in various food crops area, production, and yield. As a next step in this section our aim to investigate the effect of climate variability on the instability status of major food crops across different districts in India. As mentioned in the previous section high extent of instability was observed in the food crops area, production and yield however a **considerable variability exists in the instability status of food crops across different crops and districts.** To understand the effect of climate variability on instability status of food crops, the distribution and extent of climate variability across districts in India was estimated. This was done by employing the standard method for normalized index, cross tabulation, and spatial analysis techniques. Furthermore, the effect of climate variability on instability was estimated by applying econometrics methods of estimation such as regression analysis and chi-square method of independence. The initial results of the study indicate that **climate variability has a significant effect on the instability index of major food crops in India.** The econometric analysis suggests that the impact of climate variability on food crops instability is nonlinear and varies across different districts. In addition, the study highlights the need for climate adaptation strategies to address the adverse effects of climate variability on food crop production and ensure food security in India. The proceeding section will describe firstly district wise distribution of climate variability index across India then its effect on area, production, and yield instability of various major crops. We have analyzed the effect of climate variability on instability under following ways; a) effect on composite instability of major crops, b) effect on instability of major cereals, c) effect on instability of major millets, d) effect on instability of pulses and legumes, e) effect on instability of major oilseeds and finally estimated the effect of climate variability on food crops instability by applying econometric tools.

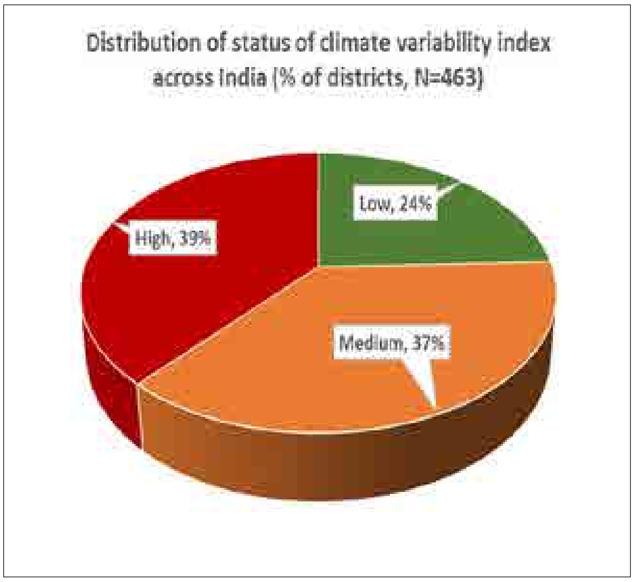
4.1. EXTENT AND DISTRIBUTION OF CLIMATE VARIABILITY ACROSS DISTRICTS IN INDIA

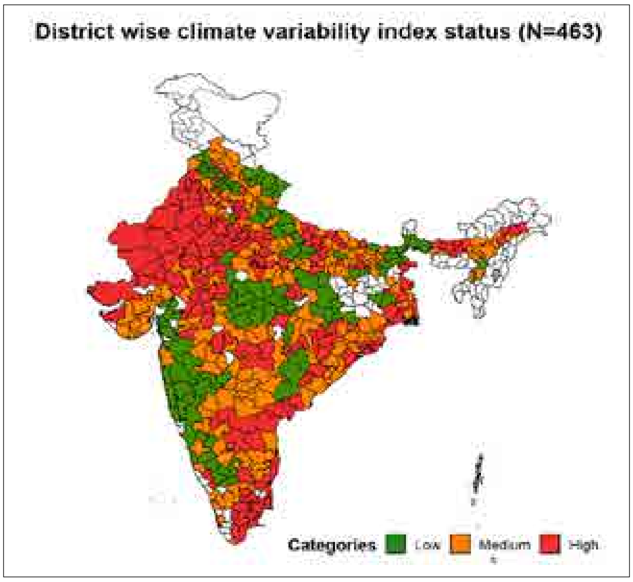
The present study assessed the extent and distribution of agro-climatic variability in **463 districts across 29 states** in India. The analysis was based on a comprehensive index that considered 26 climate indicators, as outlined in the methodology section. The index was designed to provide a detailed understanding of the extent of variability of agro-climatic conditions in different districts of the country. To ensure a fair assessment, the analysis of climate variability was undertaken at agro-ecological (AE) region basis. The entire country is classified into 14 zones based on agro-climatic indicators. The weights of different indicators of the climate variability index in each AE region were same and this considers varied nature of climatic shocks in different AE regions. The AE region level analysis also helps in identifying region specific adaptation strategies. The findings of the analysis indicate that the selected **463 districts are currently experiencing significant instability in agro-climatic indicators.** These findings highlight the need to develop targeted interventions and policies to address agro-climatic variability in various districts.

The district-wise distribution of the status of Climate Variability Index (CVI) across India has been presented in Figure 18. **A large proportion of the districts have been experiencing high (39%) and medium (37%) levels of climate variability, only about one-fourth of the districts (24%) experience low climate variability.**

It was found that most of the districts in the northern-western part of the country (especially districts of Rajasthan, Haryana, and Punjab states) experience high climate variability. These findings suggest that climate variability is a significant issue across India, and there is a need for implementing effective policies and adaptation strategies to mitigate the effect of climate change on food production.

Figure 18: District wise distribution of status of climate variability index across India (%)





Furthermore, the results provide key insights into the regional patterns of climate variability in India, which can be used by policymakers to prioritize their efforts in addressing climate change. The **districts experiencing high variability in climate are particularly vulnerable to extreme weather events such as floods, droughts, and heatwaves, which can have severe implications for agriculture, food security, and human health.** Therefore, it is crucial to implement measures that can enhance the resilience of these districts to the impacts of climate change. Overall, the study underscores the significance of understanding regional patterns of agro-climatic instability and identifying vulnerable areas to inform effective policy and decision-making. By providing insights into the instability of agro-climatic indicators and highlights the urgent need for action to address climate change in the context of food security in India, particularly in the districts facing high variability in climate.

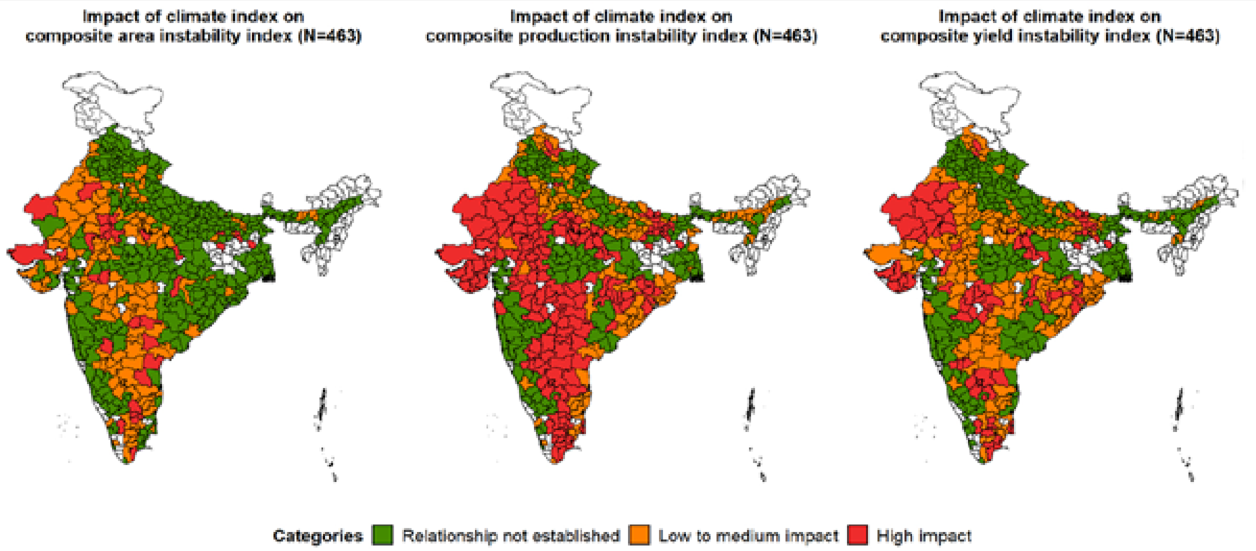
4.2. EFFECT OF CLIMATE VARIABILITY ON COMPOSITE INSTABILITY OF FOOD CROPS AREA, PRODUCTION, AND YIELD

In this section we investigate the relationship between climate change and agricultural production in India at district level. Here we examine the relationship between the extent of climate variability in a district and composite instability of all the major crops of that district. The analysis is based on the district-wise distribution of the status of the effect of climate variability on composite area, production, and yield instability as presented in Table 8 and Figure 19. The results reveal that in a **large proportion of the districts in the country the climate variability caused medium to high instability of food production.** At the same time in number of districts, the relationship between the climate variability index and the area, production, and yield instability index was not established. This indicates that **climate change may not be the only factor affecting agricultural productivity in these areas. Other factors such as soil quality, water availability, and improved agricultural technologies bridging the exiting yield gaps may also play a crucial role in determining the stability of agricultural production.** It is important to note that a considerable proportion of the districts (27 to 35%) report low to medium instability of crop area, production and yield due to of climate variability. More than one-third (37%) of the districts face high instability of crop production due to climatic variability. This implies that climate change and variability have an adverse effect on food crops area, production, and yield. In the districts where climate variability has adverse effect in terms of high instability, the agricultural production is more vulnerable to climate variability, and even small changes in climatic conditions might result in large fluctuations in production. This highlights the need for targeted interventions to improve the resilience of agricultural systems in the relevant districts. At the same time there were several districts which have high climate variability and low production instability indicating an enhanced level of resilience plausibly due to farmers increased access to improved technologies helping to adapt and bridging the existing yield gaps. Also, the climate variability and crop area instability were weakly associated. In conclusion, the present analysis provides insights into the relationship between climate change and agricultural productivity at the district level. It shows a high adverse effect of climatic variability in terms of high production instability. The highlights suggest a need for targeted interventions to improve the resilience of agricultural systems in vulnerable districts.

***Table 8**: Distribution of status of effect of climate variability on composite area, production, and yield instability (% districts)*

Impact category	Area instability index	Production instability index	Yield instability index
Relationship not established	67	36	47
Low to medium impact	27	28	35
High impact	7	37	18

***Figure 19**: Distribution of status of effect of climate variability on composite area, production and yield instability using spatial analysis*



4.3. CROP SPECIFIC EFFECT OF CLIMATE VARIABILITY ON CROP AREA, PRODUCTION AND YIELD INSTABILITY

4.3.1. Effect on instability in major cereals- rice, wheat, and maize

Rice, wheat and maize are the big three cereals and the major stay of food security. We examined the relationship between Climate Vulnerability Index (CVI) and the instability of crop area, production and yield of each of these three cereals to understand the effect of climate change on these important crops. The effect of CVI on the instability of crop area, production, and yield is presented in Table 9 and Figure 20 to Figure 22 as percent of districts affected in terms of low to medium or high effect. It was revealed that in many districts the crop area instability of rice (76% of the districts), wheat (64%) and maize (61%) did not experience a visible relationship with CVI. However, the CVI had a low to medium or high effect of production instability of all the three major cereals in more than 50% of the districts. The maize crop was relatively more impacted where climate variability resulted in production and yield instability in majority of the maize growing districts. **For rice and wheat, which are mostly irrigated crops, about one-third of the districts the production and yield instability was associated with climate variability.**

***Table 9**: Effect of climatic variability on area, production, and yield instability of major cereals (% districts)*

Particulars	Effect categories	Rice (N = 338)	Wheat (N = 273)	Maize (N = 183)
Area instability	Relationship not established	76	69	61
	Low to medium impact	19	22	23
	High impact	4	8	16
Production instability	Relationship not established	46	48	34
	Low to medium impact	33	29	22
	High impact	20	23	44
Yield instability	Relationship not established	64	63	38
	Low to medium impact	22	31	36
	High impact	14	6	26

Figure 20: District wise status of effect of climate variability on area, production, and yield instability of rice

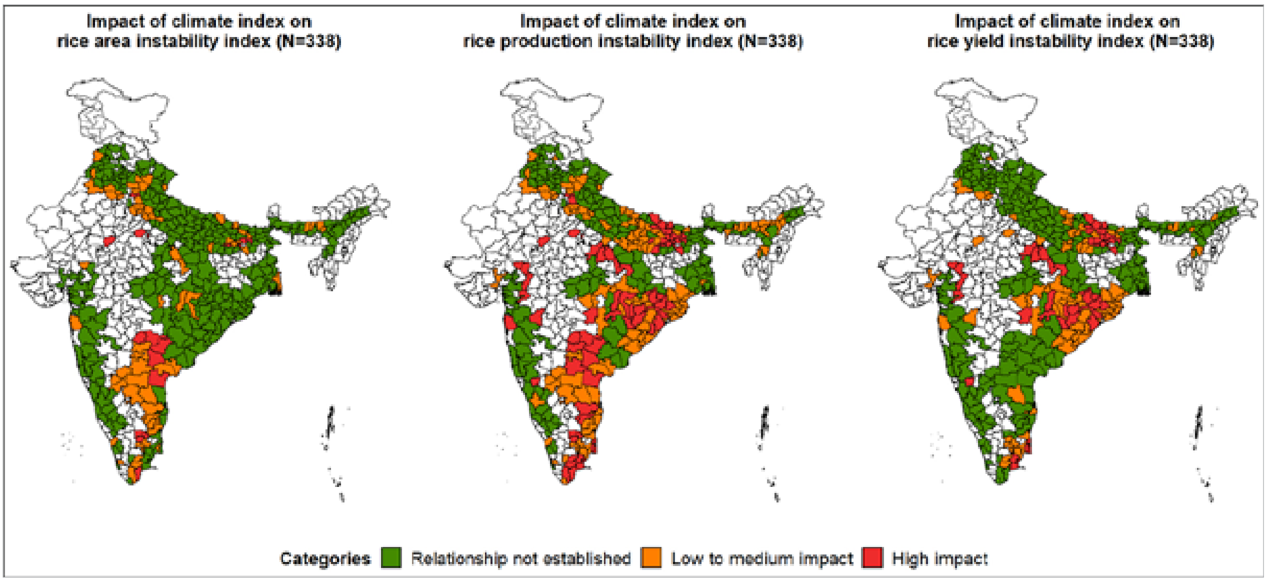


Figure 21: District wise status of effect of climate variability on area, production, and yield instability of wheat

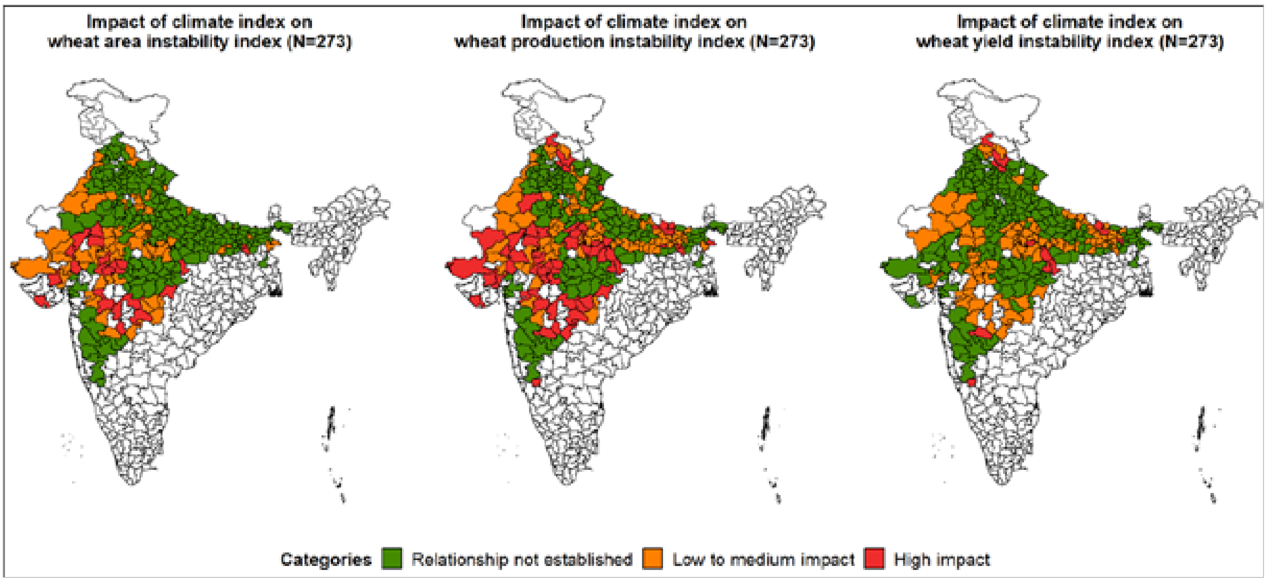
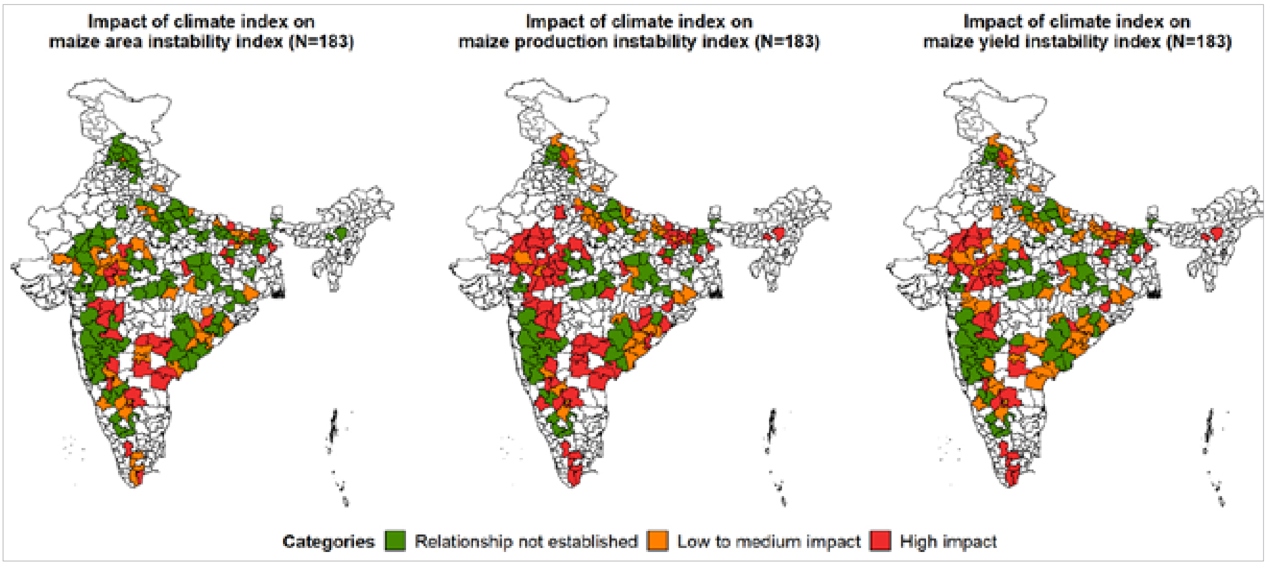


Figure 22: District wise status of effect of climate variability on area, production, and yield instability index of maize



4.3.2. Effect of climate variability on millets area, production, and yield instability

Millets are important crops for the food security of millions of people living in arid and semi-arid regions of the world. We have examined the relationship between Climate Variability Index (CVI) and area, production and yield instability of different millet crops which is presented in Table 10 and Figur 23 to Figure 26. Though the millets are considered climate resilient crops, however this analysis shows that the climate variability results in area, production, and yield instability of millets in number of districts. The finger millet crop was relatively less affected as compared to pearl millet and sorghum.

The climate variability was related to high instability in millets production as high as 56% of the districts for sorghum-kharif, 51% for pearl millet, 50% for sorghum-rabi and 46% for finger millet. However, it relates to high instability of millets crop only in 16-21% of the millet growing districts.

Overall, these results underscore the need for further research to better understanding the impact of climate change and develop appropriate strategies to mitigate the impact of climate change and variability even on millet crops which are important for the food security of people in vulnerable regions.

***Table 10**: Effect of climatic variability on area, production, and yield instability of millets (% districts)*

Particulars	Categories	Pearl millet (N=99)	Finger millet (N=38)	Sorghum-kharif (N=62)	Sorghum-rabi (N=38)
Area	Relationship not established	49	63	42	50
	Low to medium impact	32	18	42	29
	High impact	18	18	16	21
Production	Relationship not established	20	42	23	34
	Low to medium impact	29	16	21	16
	High impact	51	42	56	50
Yield	Relationship not established	28	61	23	37
	Low to medium impact	42	24	35	42
	High impact	29	16	42	21

***Figure 23**: District wise status of effect of climate variability on area, production, and yield instability of pearl millet*

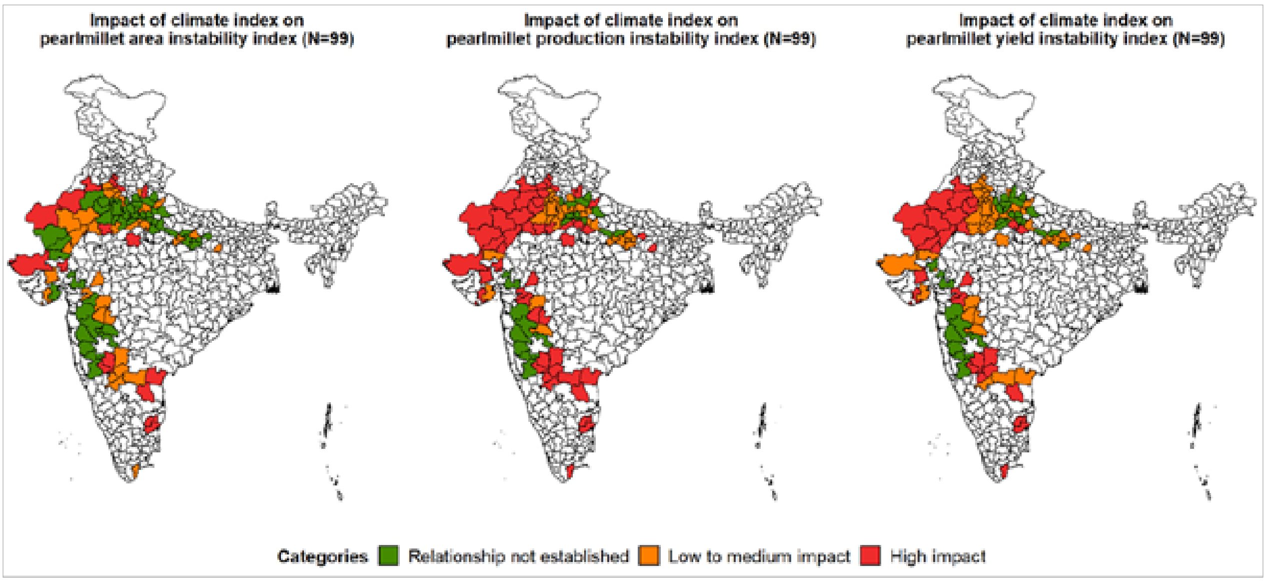


***Figure 24**: District wise status of effect of climate variability on area, production, and yield instability of finger millet*

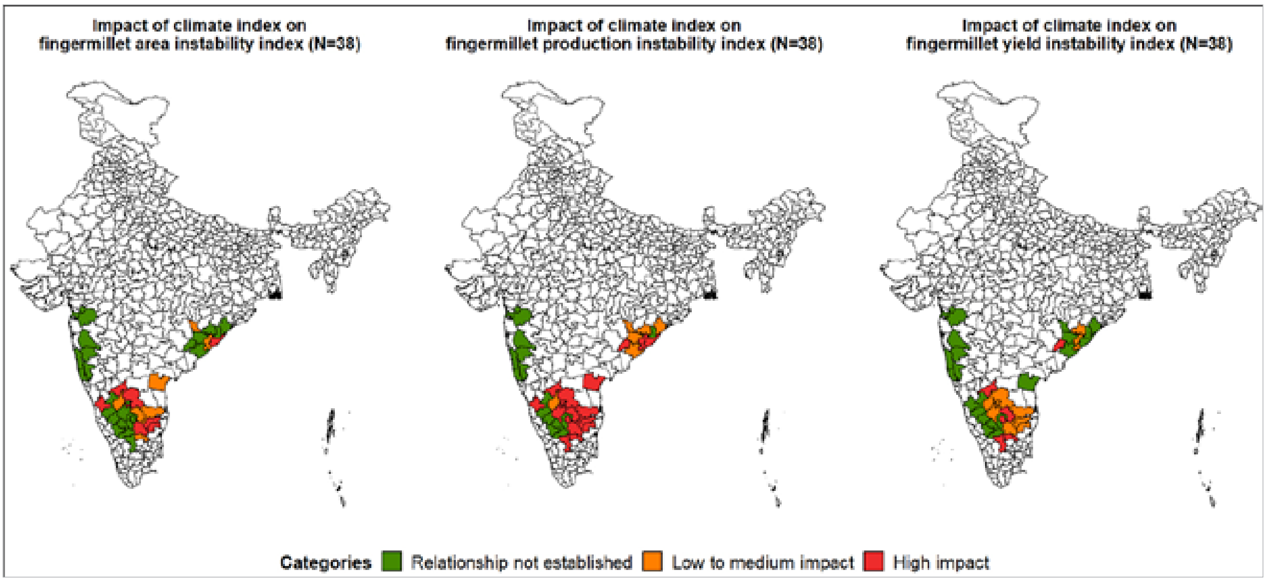


***Figure 25**: District wise status of Impact of effect of climate variability on area, production and yield instability of sorghum-kharif*

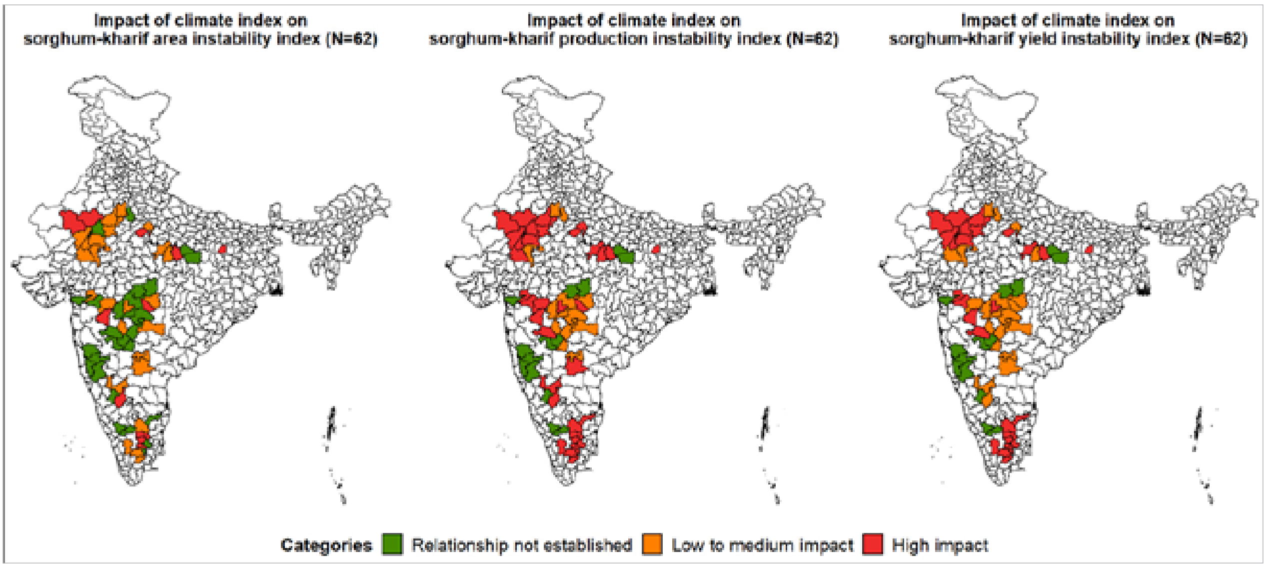
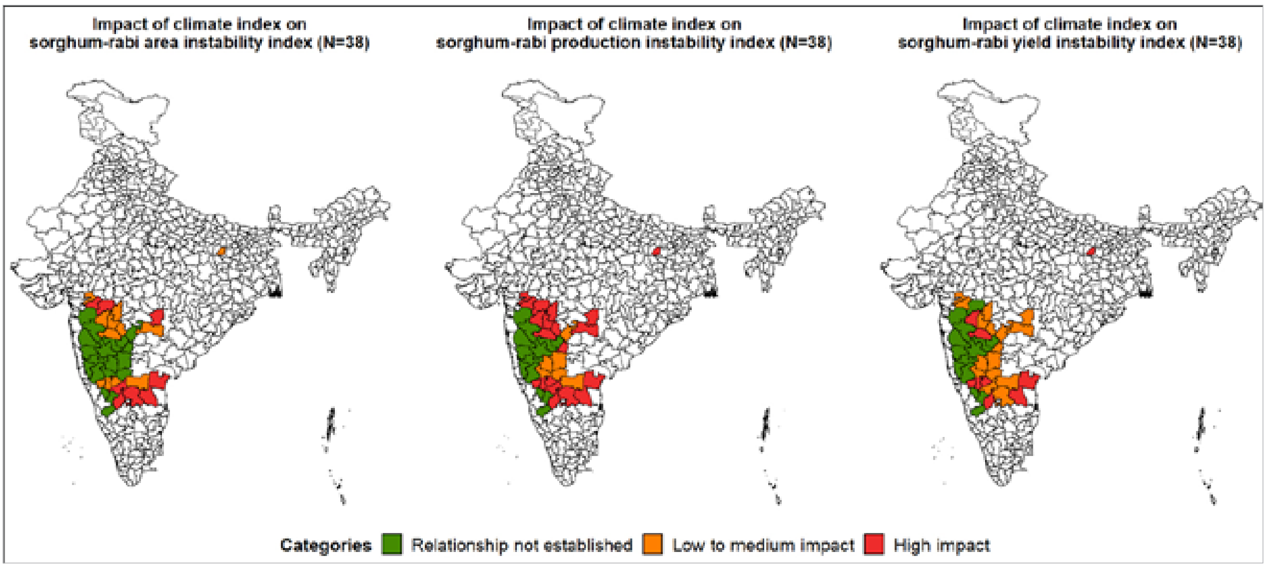


***Figure 26**: District wise status of Impact of effect of climate variability on area, production, and yield instability of sorghum-rabi*



4.3.3. Effect of climatic variability on area, production and yield instability of pulses and legumes

In this section we examine the effect of climate vulnerability on area, production, and yield instability of important legume crops such as chickpea, pigeon pea, and soybean which is presented in Table 11 and Figure 27 to Figure 29.

Our analysis shows that the relationship between climate variability and instability of crop area of these three legumes though was not established in a significant proportion of districts growing chickpea (36%), pigeon pea (56%), and soybean (58%). However, the climatic variability results in high instability of production for all three legumes in the majority of the crop growing districts. Similarly, the yield instability of three legume crops is positively related to climate variability.

In overall, the analysis shows that while the relationship between climate variability and crop production instability varies across districts, a **significant proportion of districts have experienced a high impact of climate variability on crop production instability.** This analysis provides useful evidence to design context specific policies to harness the potential of legume production in more resilient districts and interventions to manage risk and enhance resilience of legume production in districts more affected due climate variability.

***Table 11**: Impact of CVI on area, production and yield instability of pulses and legumes (in %)*

Particulars	Categories	Chickpea (N=134)	Pigeon pea (N=119)	Soybean (N=59)
Area	Relationship not established	31	56	58
	Low to medium impact	28	31	22
	High impact	41	13	20
Production	Relationship not established	24	34	37
	Low to medium impact	13	16	8
	High impact	63	50	54
Yield	Relationship not established	28	36	37
	Low to medium impact	51	24	22
	High impact	21	40	41

***Figure 27**: District wise status of effect of climate variability on area, production and yield instability of chickpea*

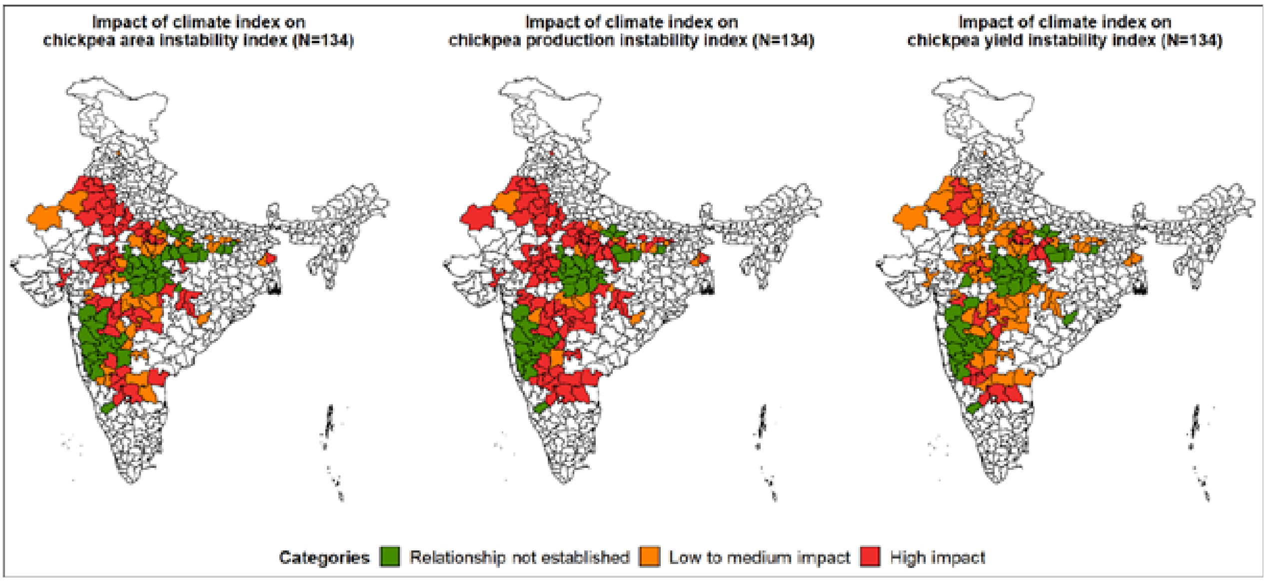


Figure 28: District wise status of effect of climate variability on area, production, and yield instability of pigeon pea

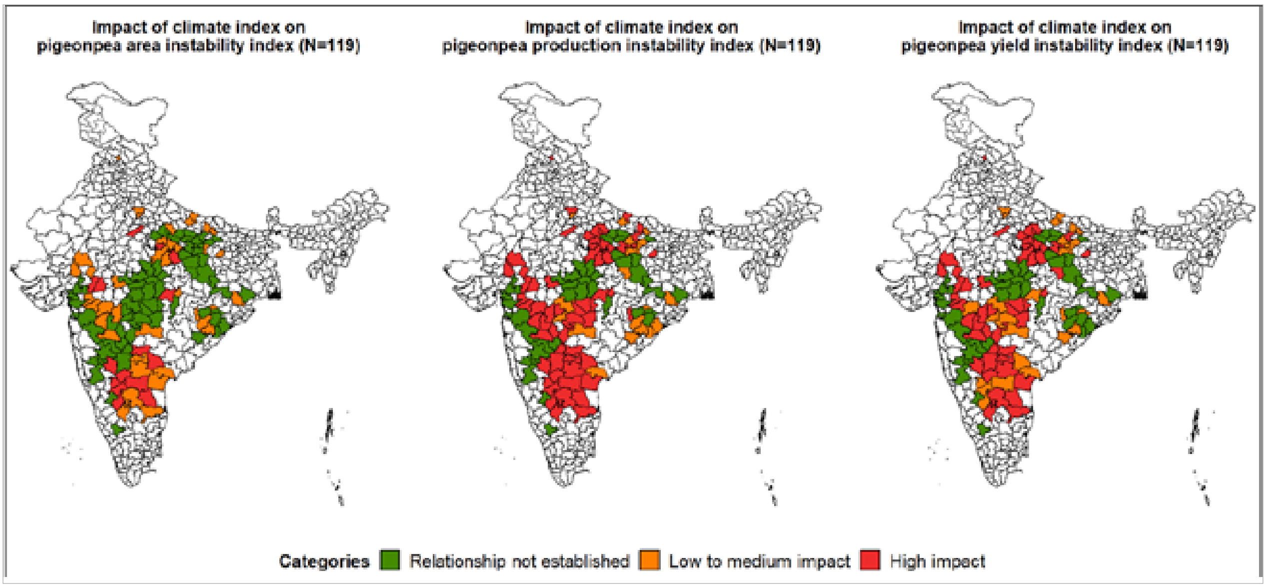
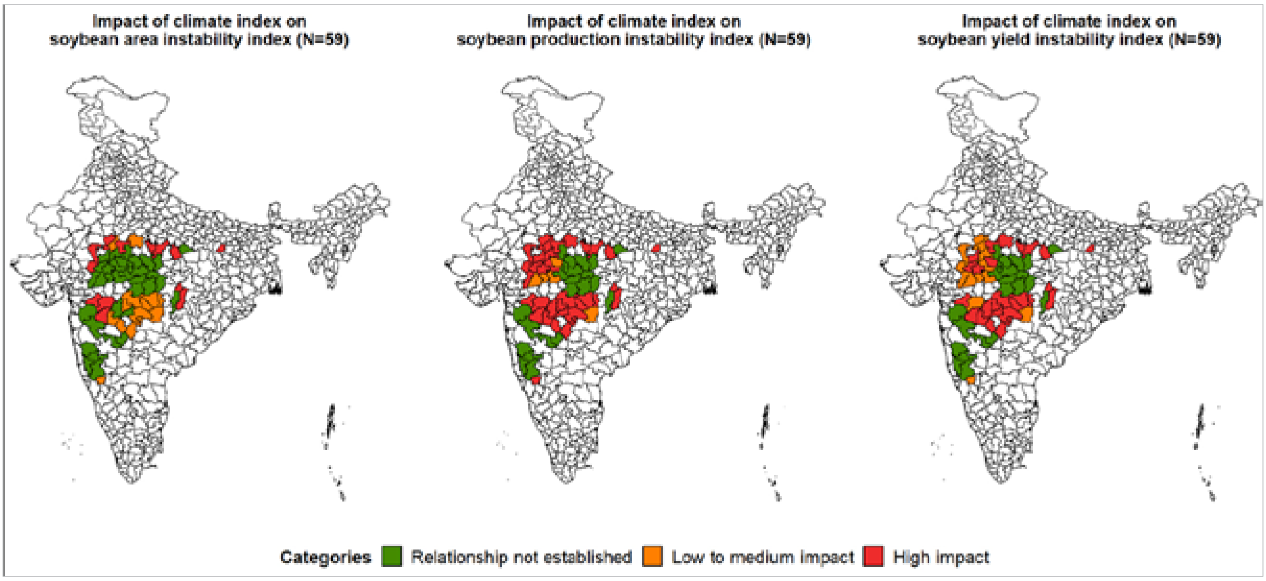


Figure 29: District wise status of effect of climate variability on area, production, and yield instability of soybean



4.3.4. Effect of climate variability on oilseeds area, production, and yield instability

Enhancing oilseed production is one of the highest policy priorities of the country due to its big and increasing import bill. Instability in the production of oilseeds is one of the reasons of their price fluctuations. We have analyzed the effect of climate Vulnerability on area, production and yield instability in rapeseed and mustard, sesame, and groundnut crops (Table 12 and Figure 30 to Figure 32). Among the three crops **sesame is the most vulnerable crop due to climate variability.** In most of the sesame growing districts climate variability is associated with high instability of crop area (53% districts), production (71%) and yield instability (45%). Though the rapeseed a & mustard and groundnut are relatively less impacted however the climate variability was associated with high yield instability of rapeseed& mustard in 39% of the districts and 49% of the groundnut growing districts.

In conclusion, the adverse impact of climate change on production of oilseeds can be considered a pressing challenge that requires urgent attention from policymakers, researchers, and other stakeholders. Therefore, it is imperative to develop and implement adaptation strategies that can mitigate the adverse effects of climate change on agricultural production and ensure food security for the growing population in India.

***Table 12**: Effect of climate variability on area, production, and yield instability of oilseeds (% districts)*

Particulars	Categories	Rapeseed & mustard (N=161)	Sesame (N=94)	Groundnut (N=124)
Area	Relationship not established	41	24	35
	Low to medium impact	34	22	47
	High impact	25	53	18
Production	Relationship not established	20	20	20
	Low to medium impact	40	9	31
	High impact	39	71	49
Yield	Relationship not established	40	28	35
	Low to medium impact	53	28	43
	High impact	6	45	23

***Figure 30**: District wise status of Impact of climate variability on area, production, and yield instability of rapeseed & mustard*

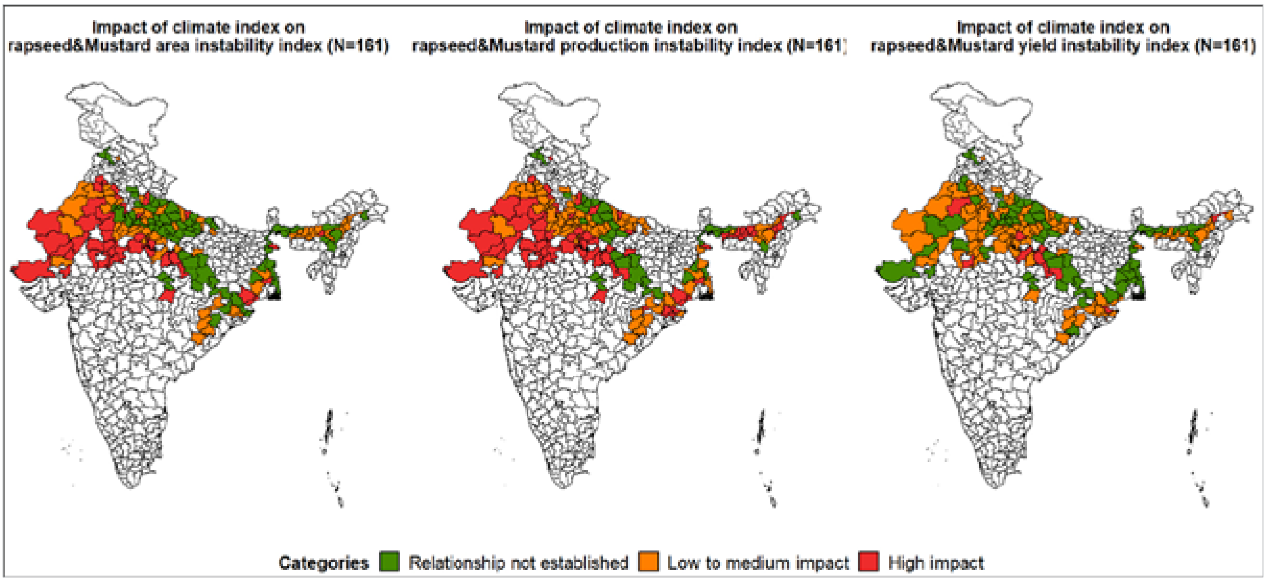


***Figure 31**: District wise status of impact of climate variability on area, production, and yield instability index of sesame*

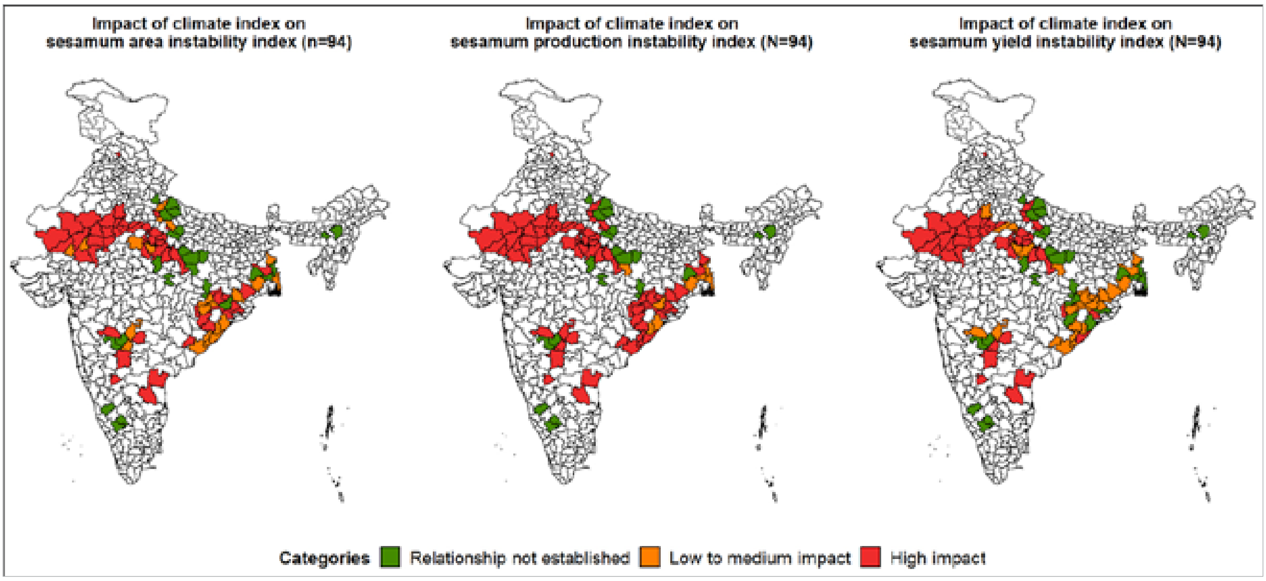
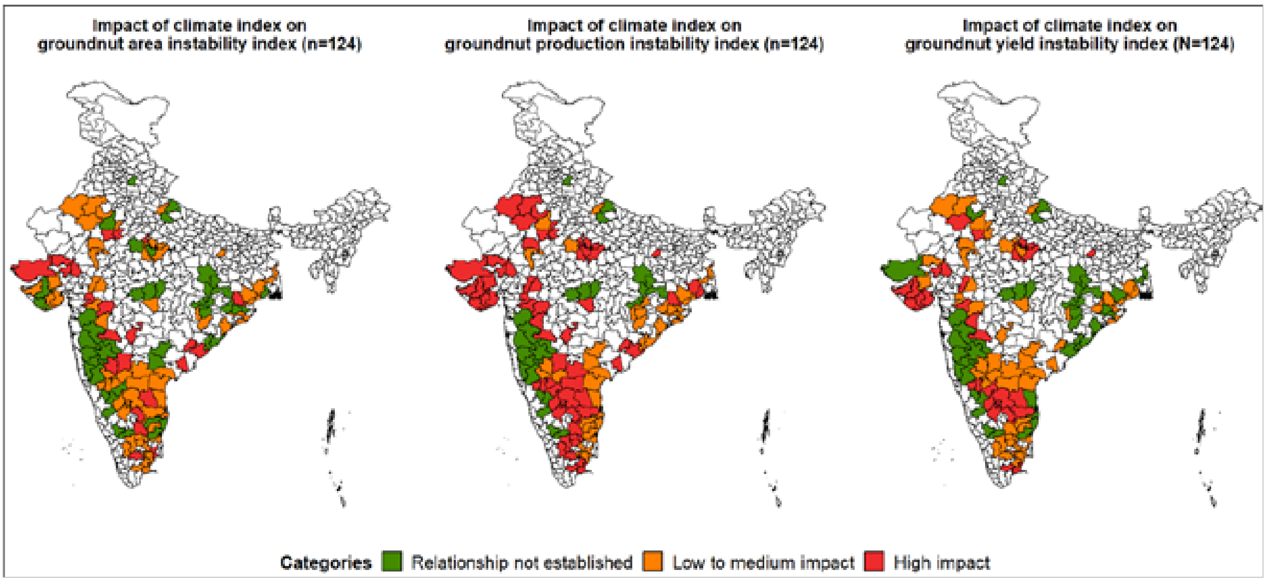


Figure 32: District wise status of impact of climate variability on area, production, and yield instability of groundnut



4.4. UNDERSTANDING THE EFFECT OF CLIMATE VARIABILITY ON AREA, PRODUCTION AND YIELD INSTABILITY OF VARIOUS CROPS USING ECONOMETRICS ANALYSIS

The observational study of the district wise climate variability map and the area, production and yield instability maps of various crops has clearly established a strong direct relationship between climate variability and crop instability. In the present section we have further investigated the effect of climate change and variability on crop instability using econometric analysis which is presented in Table 13. It presents the status of absolute effect of Climate Variability on area, production, and yield instability of various food crops. The analysis has been done both for instability of individual crops as well as instability of major crops compositely in a particular district. The results of the regression analysis show that **climate variability has significant and positive impact on instability of production and yield of major crops compositely.** This indicates that climate variability significantly increases production and yield instability of major food crops in a composite way. However, the climate variability and instability of food crops area in a composite way was not significantly associated. These results can be well explained as the crop sowing decisions are taken well before the climate extremities struck and thus the affects are greater on the crop production and yield as compared to the crop area.

The analysis for individual crops shows that the climate variability resulted in significant increase in the instability of crop area for chickpea, rapeseed & mustard, and sesame. It is plausible because these three crops are cultivated in relatively drier area and their sowing decisions are influenced by climatic factors. Further the **climate variability significantly impacted the yield instability of maize, pearl millet and kharif-sorghum.** The climatic variability also resulted in an increase in instability of production for rabi-sorghum, kharif-sorghum, pearl millet and chickpea. The **rainfed crops and the rabi crops which are grown utilizing conserved moisture were impacted in terms of their instability.** Interestingly, pigeon pea in low rainfall zones had no significant impact on area, production, or yield instability. However, the climatic variability in the higher rainfall zone had a beneficial effect on pigeon pea instability. This might be possible because increased frequency of dry spells in the higher rainfall zone might have helped pigeon pea crop. In the district level analysis, the irrigated crops were not found to be instable due to climatic variability in the econometric analysis. Besides climatic variability, there are other **sources of instability for the irrigated crops like wheat and rice e.g. electricity supply, timely availability of fertilizers and seed, market price, etc.** Since wheat and rice crops are considered sensitive to climate variability, there is need to undertake micro level analysis (see box-1) to realistically understand the impact of climatic variability on instability of crop production.

The impact of the Climate Vulnerability Index (CVI) on area, production and yield instability of various food crops were assessed using chi-square independency analysis to determine the relative impact and presented in Table 14. The results of the chi-square independency analysis also had trends like the econometric regression analysis. Climate variability has significant and positive impact on instability of production and yield of major crops compositely.

It revealed that the instability of crop area and yield compositely covering all major crops of a particular district was dependent on magnitude of climatic variability. In the case of wheat, it was dependent on the impact of climatic variability on production and yield instability, but independent of area instability. Pearl millets and sorghum-kharif were dependent on the impact of CVI on area and yield instability, but independent of production instability. Chickpea was dependent on the impact of CVI on area and yield instability, but independent of production instability. Pigeon pea was dependent on the impact of CVI on area instability, but independent of production and yield instability. Rapeseed & mustard and sesame were dependent on the impact of CVI on area instability, but independent of production and yield instability. Groundnut was independent of CVI impact on all three variables.

The results from Table 13 and Table 14 show a significant absolute and relative impact of climate variability on instability of different crops, however it varies across crops and attributes. The **study provides a broader understanding of the impact of climate variability on instability of food crop production which will be helpful in designing appropriate adaptation strategies.** However, there is need for micro level studies complementing the district level analysis for designing effective adaptation strategies.

Table 13*: Estimating absolute impact CVI on area, production and yield instability of various food crops applying regression analysis method*

Crop group	Crop Name	Area	Production	Yield
Composite index		NSI	(+) SI	(+) SI
Major cereals	Rice	NSI	NSI	NSI
	Wheat	NSI	NSI	NSI
	Maize	NSI	NSI	(+) SI
Millets	Pearl millets	NSI	(+) SI	(+) SI
	Finger millets	NSI	NSI	NSI
	Sorghum-kharif	NSI	(+) SI	(+) SI
	Sorghum-rabi	NSI	(+) SI	NSI
Pulses and legumes	Chickpea	(+) SI	(+) SI	NSI
	Pigeon pea (high rainfall zone)	(-) SI	(-) SI	NSI
	Pigeon pea (low rainfall zone)	NSI	NSI	NSI
	Soybean	NSI	NSI	NSI
Oilseeds	Rapeseed & mustard	(+) SI	NSI	NSI
	Sesame	(+) SI	NSI	NSI
	Groundnut	NSI	NSI	NSI

Note: *(i) coefficients are significant at 5% level*

(ii) NSI = no significant impact, (+) = positive significant impact, (-) SI = negative significant impact

***Table 14**: Estimating relative impact of CVI on area, production and yield instability using chi-square independency* analysis*

Crop group	Crop Name	Area	Production	Yield
Composite index		dependent		dependent
Major cereals	Rice			
	Wheat		dependent	dependent
	Maize			
Millets	Pearl millets	dependent		dependent
	Finger millets			
	Sorghum-kharif			dependent
	Sorghum-rabi			
Pulses and legumes	Chickpea		dependent	
	Pigeon pea	dependent		
	Soybean			
Oilseeds	Rapeseed & mustard			
	Sesame	dependent		dependent
	Groundnut			

**: The null hypothesis of the analysis is; H_0 = level of instability categories of area, production and yields were independent of categories of CVI individually*

Discussion and Policy Implications

This study provides valuable insights into the instability of food crops in India and its relationship with climate change enriching our understanding on the effect of climate variability and change on instability of major food crops in India in terms of area, production, and yield across 463 districts. The overall relationship has been captured through composite instability index for crop area, production and yield and climate variability index for each district. The analysis clearly shows that **climatic variability has been resulting in high instability in food crops production and yield. However, its impact on crop area instability was low to medium.** Increase in instability in food crops production due to climate change is cause of concern for the food security of the country. This calls for context specific adaptation strategies that can improve the resilience of food crops production under climate change scenario. At the individual crop level, the **maize crop shows the highest level of instability in terms of both acreage and production due to climatic variability, while rice has been the most stable among major cereals.** Similar trends have been reported by Birthal et al., 2015 also. The district level analysis did not show impact of climatic variability on instability of area and production of wheat. It may be due to two reasons: i. wheat is mostly an irrigated crop and farmers are probably able to adapt, maybe incurring more cost of production on adaptation strategies; ii. some part of a district is impacted and others are not which masks the impact of climate variability at district level. Moreover, climate change may not be the only factor affecting agricultural productivity, other factors might be more important in certain districts. Therefore, there is **need to undertake more in-depth household level analysis to fully understand the impact of the climatic variability and change on food crops production.** This district level analysis can be used to identify sites for undertaking village/household level study targeting most vulnerable regions (Annexure 1).

The **rainfed food crops such as rabi-sorghum, kharif sorghum, pearl millet, chickpea, pigeon pea and sesame which are considered more climate resilient were found to have high instability due to climatic variability.** These rainfed crops are not only critically important for the food and livelihoods security in the relatively more vulnerable regions but also highly nutritious. Therefore, a high **policy priority is needed to build resilience in dryland food crops production.** The targeted interventions are needed to improve the resilience of agricultural systems in vulnerable districts, including the development and promotion of drought tolerant crop varieties and cultivars, sustainable farming practices, and the provision of context specific climate information services for farmers and cross the agricultural value chains.

The implications of the study for policy development and agricultural management in India are significant. The information obtained can be used to develop adaptation strategies to minimize climatic induced instability of food production. Policymakers can use this information to identify the areas that require immediate attention and develop policies and programs accordingly. The map can also be used by farmers and other stakeholders to identify the best areas for cultivation based on the level of instability in the district.

Given the global concern about the impact of climate change on agriculture, the **study highlights the need for targeted interventions to improve the resilience of agricultural systems in the districts where climate change has a high impact on production instability.**

Overall, this study contributes to the understanding of crop instability in India and its relationship with climate change. Further research is needed to explore the factors that contribute to crop instability in India and the effectiveness of different interventions in addressing this issue. The findings of this study have implications for policy decisions and agricultural management practices in India and other countries facing similar challenges.

The study has some limitations, such as not considering the impact of pests and diseases on crop stability and focusing only major food crops. Future studies should consider these factors and examine the stability of other crops to gain a more comprehensive understanding of the impact of climate change on agricultural production in India.

Image courtesy: pixabay.com

References

Aggarwal, P. K. (2008). Global climate change and Indian agriculture: impacts, adaptation, and mitigation. *Indian Journal of Agricultural Sciences*, *78*(11), 911.

Alpino, T. D. M. A., Mazoto, M. L., Barros, D. C. D., & Freitas, C. M. D. (2022). The impacts of climate change on Food and Nutritional Security: a literature review. *Ciência & Saúde Coletiva*, *27*, 273-286.

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95-96.

Birthal, P. S., Negi, D. S., Khan, Md. T., & Agarwal, S. (2015). Is Indian agriculture becoming resilient to droughts? Evidence from rice production systems. Food Policy, 56, 1–12. https://doi.org/ https://doi.org/10.1016/j.foodpol.2015.07.005

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. J. N. F. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198-209.

Cuddy, J. D., & Valle, P. D. (1978). Measuring the instability of time series data. *Oxford bulletin of economics and statistics*, *40*(1), 79-85.

Datta, P., Behera, B., & Rahut, D. B. (2022). Climate Change and Indian Agriculture: A Systematic Review of Farmers' Perception, Adaptation, and Transformation. Environmental Challenges, 8.

Firdaus, R. R., Senevi Gunaratne, M., Rahmat, S. R., & Kamsi, N. S. (2019). Does climate change only affect food availability? What else matters?. *Cogent Food & Agriculture*, *5*(1), 1707607.

Godde, C. M., Mason-D'Croz, D., Mayberry, D. E., Thornton, P. K., & Herrero, M. (2021). Impacts of climate change on the livestock food supply chain; a review of the evidence. *Global food security*, *28*, 100488.

Guiteras, R. (2009). The impact of climate change on Indian agriculture. *Manuscript, Department of Economics, University of Maryland, College Park, Maryland*.

Krishna Kumar, K., Rupa Kumar, K., Ashrit, R. G., Deshpande, N. R., & Hansen, J. W. (2004). Climate impacts on Indian agriculture. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *24*(11), 1375-1393.

Kumar, S., Raju, B. M. K., Rao, C. A., Kareemulla, K., & Venkateswarlu, B. (2011). Sensitivity of yields of major rainfed crops to climate in India. *Indian Journal of Agricultural Economics*, *66*(902-2016-67305).

Mall, R. K., Singh, R., Gupta, A., Srinivasan, G., & Rathore, L. S. (2006). Impact of climate change on Indian agriculture: a review. *Climatic change*, *78*, 445-478.

Nema, P., Nema, S., & Roy, P. (2012). An overview of global climate changing in current scenario and mitigation action. *Renewable and Sustainable Energy Reviews*, *16*(4), 2329-2336.

Praveen, B., & Sharma, P. (2020). Climate change and its impacts on Indian agriculture: An econometric analysis. *Journal of Public Affairs*, *20*(1), e1972.

Sanober, N. (2023). An overview of the influence of climate change on food security and human health. Archives of Food and Nutritional Science, 7(1), 001–011. https://doi.org/10.29328/journal.afns.1001044

Shaw, D. J. (2007). World food summit, 1996. In World Food Security: A History since 1945 (pp. 347-360). London: Palgrave Macmillan UK.

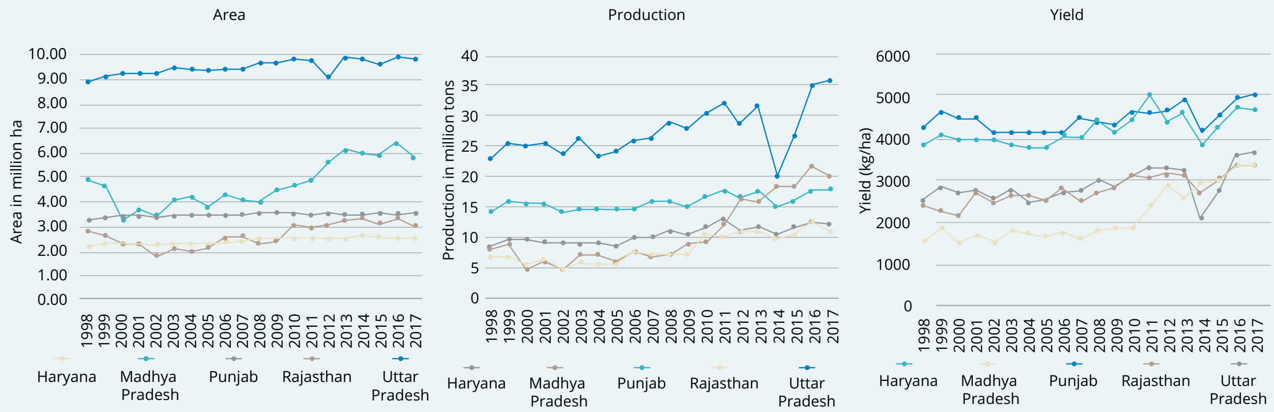
VijayaVenkataRaman, S., Iniyan, S., & Goic, R. (2012). A review of climate change, mitigation, and adaptation. Renewable and Sustainable Energy Reviews, 16(1), 878-897.

P.S. Birthal, D.S. Negi, M.T. Khan, S. Agarwal 2015. Is Indian agriculture becoming resilient to droughts? Evidence from rice production systems, Food Policy., 56, pp. 1-12, 10.1016/j.foodpol.2015.07.005

BOX

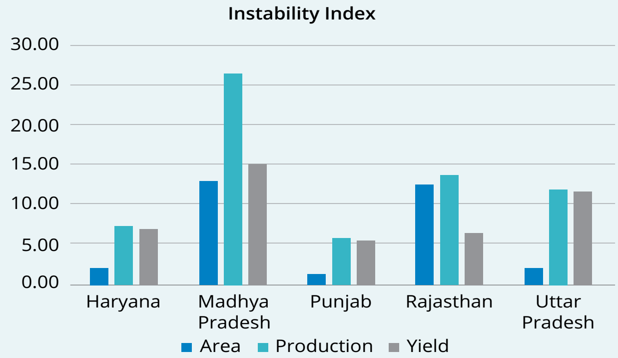
Investigating what happened to wheat area, production and yield trends and instability in five major wheat producing states in India

Figure B1: *Trend of area production and yield over time (1998-2017)*



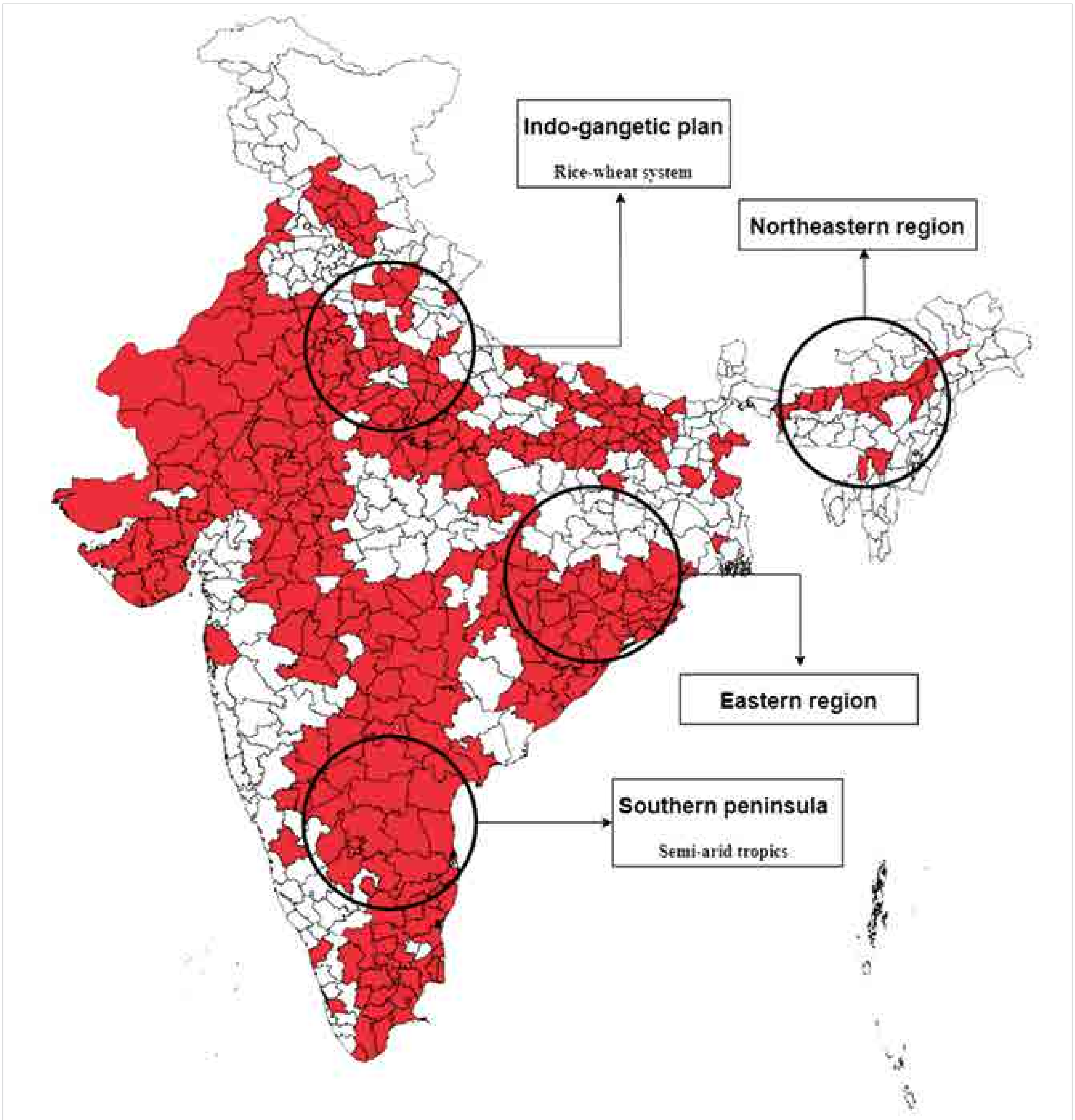
Wheat is a winter (rabi) crop sown in November–December and harvested in March–April and the crop fully relies on irrigation because of low precipitation during winter. No unusual fluctuation has been observed in the area, production and yield of wheat crop during the past 20 years (1998-2017) in five major wheat producing states except in the year 2014 due to unseasonal rain and hailstorm in Feb-March which impacted rabi crops ***(Times of India- Foodgrain production during 2014-15 crop year declines***). During the past 20 years' overall instability of wheat area, production and yield also fall under low categories in all the four states except Madhya Pradesh which shows low instability for crop area and medium instability for production and yield. The climate data clearly shows that there has been significant climate variability during this period including terminal heat stress, unseasonal rain and others which could have impacted wheat production and yield. The low or medium level of instability in area, production and yield in the five major wheat-growing states indicates that wheat crop appears to be relatively climate resilient. However, it might be possible that there may be intra-district variability in impacts, some parts of the districts are impacted due to climate extremes and others are not impacted, so the averaging out of the data at district and state level might have masked the actual impacts on climate change on wheat production. Hence, we argue that there is a need to evaluate the impact of climate change by undertaking micro and households level analysis.

Figure B2: *Area, production, and yield instability*



Annex

Potential sites for the micro level study in the second phase of the project



Note: Production instability of the highlighted districts are highly impacted by climate variability index

Notes

Notes

Notes

World Food Programme
India Country Office
2 Poorvi Marg, Vasant Vihar, New Delhi-110057, India
T +91 11 46554000
https://www.wfp.org/countries/india

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Hyderabad,
Telangana, India
https://www.icrisat.org/