Influence of climate change on agricultural sustainability in India: 
A state-wise panel data analysis

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Abstract. Singh AK, Kumar S, Jyoti B. 2022. Influence of climate change on agricultural sustainability in India: A State-wise panel data analysis. Asian J Agric 6: 15-27. This study developed Economic Efficiency Index (EEI), Social Equity Index (SEI) and Ecological Security Index (ESI) as an assessment of Agricultural Sustainability Index (ASI) in 17 Indian states during 1990-2017. The Composite Z-Score method was used to integrate 32 different economic, social, and ecological security factors to create ASI, EEI, SEI, and ESI. Subsequently, it examined the impact of climatic factors on ASI using linear, log-linear, and non-linear regression model through state-wise panel data during the said period. The descriptive results indicate that agricultural sustainability was positively associated with economic efficiency, social equity, and ecological security. Therefore, factors related to economic efficiency, social equity and ecological security would be helpful to improve sustainability in the Indian agricultural sector. Furthermore, there was high diversity in economic efficiency, social equity, and ecological security across the Indian state. The ratio of agriculture Gross Domestic Product (GDP) and gross irrigated area with the gross sown area, landholding size, a yield of food-grain and oilseed crops, and cropped area under food-grain crops were observed to be the most influencing factors of economic efficiency. Total literacy rate, female literacy rate and rural literate population were the most crucial factors to improve social equity. Ecological security was improved with increased forest area, pastureland and cropping intensity. Furthermore, the empirical results also showed that maximum temperature had a negative influence; and economic efficiency, social equity, and ecological security positively influenced agricultural sustainability in India. Therefore, India needs to take effective climate policy action to mitigate the negative impact of climate change in the agricultural sector and its allied activities to increase sustainable agricultural development in India. Subsequently, this study provided several policy suggestions to reduce climate change risk in the Indian agricultural sector.

Keywords: Agricultural sustainability, climate change, ecological security, economic efficiency, India, social equity

Abbreviations: ASI: Agricultural Sustainability Index; CMIE: Centre for Monitoring Indian Economy; CDR: Credit Deposit Ratio; ESI: Ecological Security Index; ESI: Ecological Security Index; EDE: Economic Development Index; EEI: Economic Efficiency Index; EnSI: Environmental Sustainability Index; GoI: Government of India; GHGs: Greenhouse Gases; GDP: Gross Domestic Product; IMD: Indian Meteorological Department; OECD: Organization for Economic Co-operation and Development; RBI: Reserve Bank of India; SEI: Social Equity Index; VIF: Variance Inflation Factor

INTRODUCTION

The agricultural sector is a sole sector to meet the food demand of people, provide raw material to industries, and create employment for agricultural laborers, and give fodder to livestock. Although, at present agriculture sector is facing several challenges due to overwhelming population growth, industrialization, urbanization, scarcity of ecosystem services, decreasing size of landholding, rising cost of cultivation, shifting of farmers towards the non-agricultural sector, low agricultural R&D expenditure, insignificant support from government and climate change at a global level (Singh and Hiremath 2010; Latruffe et al. 2016; Kareemulla et al. 2017; Kumar et al. 2017; Bakari et al. 2018; Singh and Issac 2018; Lampridi et al. 2019; Mili and Martínez-Vega 2019). Furthermore, the world’s population is expected to reach 11.2 million by 2100 (Lampridi et al. 2019). Thus, the agriculture sector will be vulnerable due to the activities above in the future. Hence, there is an urgency to implement conducive policies to increase agricultural sustainability worldwide.

The notion of sustainability of the agriculture sector is that it meets the food security of people and can maintain the farmers' profitability, provide fodder to all livestock in the long-term, tolerate the negative impact of soil degradation, socio-economic demand, and gradually degrading environment (Hensen 1996). Also, it includes farming methods that do not negatively affect the environment and economic accessibility of farmers (Rostami and Mohammadi 2017). Moreover, it maintains the economic viability and social welfare as sustaining the quality of natural resources (Hensen 1996). It also integrates the environment, economic efficiency and social equity to increase food production (Gaetano 2010; Fallah-Alipour et al. 2018). Existing researchers have defined agricultural sustainability and used its indicators as per their views. For instance, Gomez et al. (1996) and Hensen (1996) have argued that the agricultural system can be...
sustainable when it can meet the farmer’s need for productivity, profitability, stability and social equity, and preserves the quality of natural resources.

Agricultural sustainability is a situation in which a firm efficiently produces enough food for people without damaging the ecosystem services (Asadi et al. 2013). Agricultural sustainability may be defined as efficient and optimum food-grain and non-food-grain crops that do not negatively impact ecosystem services and human health (Kareemulla et al. 2017). Fallah-Allipour et al. (2018) defined agricultural sustainability as protecting the environment and improving the agricultural production and human well-being. Furthermore, several studies have claimed that agricultural sustainability includes socioeconomic and bio-ecological dimensions (De Koeijer et al. 2002; Sharma and Shardendu 2011; Talukder et al. 2020). Factors associated with the environment, social and economic development are also the determinants of agricultural sustainability (Latruffe et al. 2016; Ryan et al. 2016; Lampridi et al. 2019; Mili and Martínez-Vega 2019). Therefore, agricultural sustainability can be achieved by maintaining economic, social and environmental development. Valizadeh and Hayati (2021) claimed that social equity, human well-being, stability, productivity and efficiency of the resources are the determinants of agricultural sustainability. Although, agricultural production activities have several negative impacts on ecosystem services (i.e., land, water, forests, air, soil-erosion, biodiversity), contributing around 31% of greenhouse gas globally (Talukder et al. 2020). Thus, achieving sustainability in the agricultural sector would be challenging to maintain environmental, economic and social development in larger agrarian economies like India and China (Zhen and Routray 2003).

In India, a large segment of society is engaged in the agricultural sector (Ghabru et al. 2017). Therefore, India must increase agricultural sustainability to meet people’s food security and provide raw materials to agro-based industries. Also, India is going to be the most populated country by 2025. Thus, there would be a requirement for more food to feed the growing population in India. In India, several studies have assessed the influence of various activities on the agricultural sector using primary and secondary data at district, state, region and country level. Most studies have examined the impact of climatic and non-climatic factors on agricultural production and productivity in India (e.g., Kumar et al. 2016, 2017). However, in India, limited studies could measure agricultural sustainability across states (except, Kareemulla et al. 2017). Few studies could assess the association of climatic factors with agricultural sustainability in India. Also, previous studies could not address the climate change impacts on agricultural sustainability in India. Due to highlighted research gap, this study addressed the following research objectives: To develop Agricultural Sustainability Index (ASI), Economic Efficiency Index (EEI), Social Equity Index (SEI) and Ecological Security Index (ESI) in Indian states for some time of 1990-2017. To examine the influence of climatic factors on estimated ASI using state-wise panel data in India.

**MATERIALS AND METHODS**

**Study area and sources of data**

For this study, 17 states of India were considered with time series of 28 years (i.e., 1990-2017). Following Indian states were considered from various regions: (i) Southern Region: Andhra Pradesh, Karnataka, Tamil Nadu and Kerala; (ii) Western Region: Gujarat and Maharashtra; (iii) Northern Region: Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab and Rajasthan; (iv) North-Eastern Region: Assam; (v) Central Region: Uttar Pradesh and Madhya Pradesh; (vi) Eastern Region: Bihar, Odisha and West Bengal.

Fertilizer consumption, gross irrigated area, gross sown area, net irrigated area, net sown area, food-grain yield, oilseed yield, food-grain area, oilseed area, forest area, permanent pasture and grazing lands, land not available for cultivation and cropping intensity were derived from the Centre for Monitoring Indian Economy (CMIE), Ministry of Agriculture and Farmers Welfare, Government of India (GoI). The average size of land holdings was taken from Agriculture Census, Department of Agriculture, Co-operation & Farmers Welfare (GoI). Per capita availability of milk production was taken from the Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture, GoI. Credit Deposit Rasio (CDR) of scheduled commercial banks, credit disbursed to agriculture by scheduled commercial banks and agriculture Gross Domestic Product (GDP) were taken from Reserve Bank of India, GoI. Gender ratio, population density, population growth and urbanization were taken from Census, GoI. Rural literate population, rural poor population, Gini coefficient of distribution of consumption, total literacy rate and female literacy rate were taken from Niti Ayog, GoI. Birth rate and infant mortality rate were taken from Office of the Registrar General and Census, GoI. Per capita net state domestic product, per capita availability of food-grain production, road length and government expenditure on social sector were derived from the website of RBI, Central Statistics Office, GoI. Annual average precipitation, Annual Average Maximum and Minimum Temperature (AAMaxT and AAMinT), and Actual Annual Rainfall (AARF) were taken from GIS online data base and Indian Metrological Department (IMD), GoI. Data for few variables (e.g., literacy rate, female literacy rate, birth rate, urbanization, population density, average size of land holding, rural literate person, rural poor people) were not available in time series. Thus, interpolation and extrapolation methods were used to compute the middle values of these variables to complete the time series of 1990-2017 (Kumar et al. 2017; Singh et al. 2019).

**Theoretical foundation on measurement of agricultural sustainability**

Previous studies have claimed that an index-based estimation is an effective tool for assessing agricultural sustainability (Zhen and Routray 2003; Sharma and Shardendu 2011; Fallah-Allipour et al. 2018; Talukder et al. 2020). The approach is useful for formulating agricultural development policies and comparing agricultural...
sustainability across regions (Valizadeh and Hayati 2021). However, different indicators have been used to create ASI in various economies using micro and macro-level information. Therefore, there is no consistent process for measuring agricultural sustainability and defining its major indicators in the existing literature (Roy and Chan 2012; Lampridi et al. 2019). Aggregation of several factors as an index for agricultural sustainability assessment was introduced by World Bank, United Nations and Organization for Economic Co-operation and Development (OECD) in the 1970s (Gaetano 2010). However, existing studies have developed several indexes such as integrated sustainability score, farm assessment index, ASI, farmers development index, sustainable livelihood security index and agricultural sustainability measurement index to assess the performance of agricultural sustainability using primary and secondary data (Qi et al. 2007; Hatai and Sen 2008; Gaetano 2010; Sharma and Sharndendu 2011; Roy and Chan 2012; Rostami and Mohammadi 2017; Kareemulla et al. 2017; Fallah-Alipour et al. 2018; Mili and Martínez-Vega 2019; Talukder et al. 2020; Valizadeh and Hayati 2021). Most studies have used simple descriptive analysis, principal components analysis and factor component analysis which includes the normalization values of a selected set of variables. In this, a study following processes was used to develop ASI:

**Segregation of indicators**

Agricultural sustainability integrates economic efficiency, social equity and ecological security-related variables (Gaetano 2010; Fallah-Alipour et al. 2018). Thus, selected indicators were divided into the categories as mentioned earlier.

**Estimation of Composite Z-Score**

It converts all values of a specific variable between 0-1 and makes relative comparisons across entities (Gaetano 2010; Fallah-Alipour et al. 2018). For example, if a variable had a positive impact on agricultural sustainability as per the available theoretical literature, then Composite Z-Score (CZS) (Kareemulla et al. 2017; Rostami and Mohammadi 2017) was estimated as follows:

\[
CZS_i = \frac{[X_{is} - Min(X_{is})]}{[Max(X_{is}) - Min(X_{is})]}
\]  

(1)

Here, CZS is the Composite Z-Score for \(i^{th}\) variable, \(s\) is cross-sectional states; \(X_{is}\) is actual value; \(Min(X_{is})\) is minimum value; \(Max(X_{is})\) is highest value for a specific variable across states in equation (1). Values of CZS for a specific variable lie between 0-1. If a factor had a negative impact on agricultural sustainability according to existing literature, the CZS (Rostami and Mohammadi 2017) was estimated as follows:

\[
CZS_i = \frac{[X_{is} - Max(X_{is})]}{[Min(X_{is}) - Max(X_{is})]}
\]  

(2)

Clarification of all variables is given in equation (1).

**Estimation of weights for arbitrary variable**

Weightage technique is useful to divide the indicators into positive or endogenous and negative or exogenous (Fallah-Alipour et al. 2018). In this study, weightage for each factor (Kumar et al. 2017; Singh and Issac 2018; Singh et al. 2019) was assigned as follows:

\[
W_i = \frac{K}{\sqrt{\sum K^2}}
\]  

(3)

Here, \(W_i\) is weightage (0<\(W_i\)<1 assigned to \(i^{th}\) variable and \(\sum W_i = 1\). \(Var(CZS)\) is a statistical variation across Composite Z-Scores for all variables in equation (3). \(K\) was measured as follows:

\[
K = \frac{1}{\sqrt{\sum (\frac{1}{\sqrt{Var(CZS)})}}}
\]  

(4)

**Aggregate sum**

It is a linear average sum of all CZS that was also multiplied by assigned weights under a specific measurement category.

**Development of Agricultural Sustainability Index (ASI)**

Agricultural sustainability has a multidimensional and complex association with all activities in a country (Valizadeh and Hayati 2021). So, agricultural sustainability assessment is controversial (Hatai and Sen 2008; Sydorovych and Wossink 2008; Fallah-Alipour et al. 2018; Lampridi et al. 2019; Mili and Martínez-Vega 2019; Talukder et al. 2020). Existing researchers do not have unanimity on the dimension of agricultural sustainability (Kareemulla et al. 2017). Current studies have also observed that agricultural sustainability is an integrated component of social, economic and ecological sustainability (Sharma and Sharndendu 2011; Latruffe et al. 2016; Ryan et al. 2016; Lampridi et al. 2019). Accordingly, EEI, SEI, and ESI can be developed to examine agricultural sustainability. Subsequently, in this study, ASI was considered as a linear average sum of EEI, SEI and ESI, which was estimated as follows:

\[
ASI_{st} = \{(EEI)_{st} + SEI_{st} + (ESI)_{st}\}/3
\]  

(5)

Here, ASI is Agricultural Sustainability Index, EEI is Economic Efficiency Index, SEI is social equality index and ESI is Ecological Security Index in equation (5).

**Economic Efficiency Index (EEI)**

A single variable may not explain economic efficiency. Thus, this study used per capita GDP as the most useful and effective representative variable for economic development. However, economic efficiency or development is a multidimensional concept, and it has a significant association with several activities of a country (Latruffe et al. 2016). Few studies have developed Economic Development Index (EDI) to assess the relative performance of economic development across countries. It is helpful for farmers to increase their profitability in agricultural sector (Gaetano 2010). Thus, economic
development is helpful to increase the productivity, profitability and stability of the agricultural production system (Zhen and Routray 2003; Latruffe et al. 2016). Therefore, this study has formulated EEI to investigate the relative economic efficiency of selected Indian states. Here, EEI was considered as a function of per capita net state domestic product, CDR of scheduled commercial banks, the ratio of credit to agriculture by scheduled commercial banks with the gross sown area, a ratio of agriculture GDP with the gross sown area, a ratio of a gross irrigated area with the gross sown area, a ratio of a net irrigated area with the net sown area, the average size of land holdings, a yield of food-grain and oilseeds crops, percentage area under food-grain and oilseeds crops, a ratio of the rural literate population with gross sown area and ratio of the rural poor population with the gross sown area. EEI was estimated as a linear sum of CZS of all associated variables that were multiplied by assigned weightages and explained as:

\[
(EEI)_{\text{st}} = W_1 \times (CZS_{PCNSDP})_{\text{st}} + W_2 \times (CZS_{CDR})_{\text{st}} + W_3 \times (CZS_{AGDPGSA})_{\text{st}} + W_4 \times (CZS_{GIA/GSA})_{\text{st}} + W_5 \times (CZS_{NIA/NSA})_{\text{st}} + W_6 \times (CZS_{ASI/GSA})_{\text{st}} + W_7 \times (CZS_{TOSY})_{\text{st}} + W_8 \times (CZS_{OASPGSA})_{\text{st}} + W_9 \times (CZS_{RPPGSA})_{\text{st}}
\]

(6)

Here, \(W_1 \ldots W_9\) are the assigned weightages and CZS is Composite Z-Score of associated variables in equation (6). The brief of economic efficiency associated variables have been given in Table 1.

Per capita income is a vital indicator for national development and prosperity (Hatai and Sen 2008). It also maintains the overall livelihood security and agricultural sustainability. Thus, per capita net state domestic product was considered to estimate EEI (Singh and Issac 2018). The CDR is helpful to increase money flow and financial stability in the domestic market, and it is a vibrant determinant of economic efficiency. Credit disbursement to the agricultural sector contributes to increasing agricultural production (Kumar et al. 2017). Value of show per hectare land is also helpful in increasing economic efficiency (Hensen 1996; Gaetano 2010; Latruffe et al. 2016; Singh and Issac 2018; Mili and Martínez-Vega 2019). Thus, a ratio of agriculture GDP with the gross sown area was used to estimate EEI. Irrigated area has high yielding capacity in cultivation (Kumar et al. 2017; Singh and Issac 2018). Hence, a ratio of gross irrigated area with the gross sown area and net irrigated area with net sown area was used to develop EEI (Ghabru et al. 2017). Farm management practices and the application of technologies can be used in large landholding. Thus, landholding size has a vital contribution to increasing agricultural sustainability (Hensen 1996; Gaetano 2010; Fallah-Alipour et al. 2018; Mili and Martínez-Vega 2019).

High yields of food-grain and oilseed crops are the fruit of better soil fertility and quality, irrigation and technological advancement (Hatai and Sen 2008; Kareemulla et al. 2017; Singh and Issac 2018). It also increases the farmers’ profitability; thus, it is a crucial determinant of agricultural sustainability (Ghabru et al. 2017). The cropped area under food-grain and oilseed crops greatly contributes towards agricultural sustainability (Kumar et al. 2017; Mili and Martínez-Vega 2019).

Though India is rich in traditional knowledge on agriculture, a literate person understands modern agricultural technologies, irrigation methods, appropriate time of planting and irrigation, and adaptation strategies to climate change in farming (Kumar et al. 2016). Thus, agricultural sustainability increases with an increase in the participation of the literate population in cultivation (Kumar et al. 2017; Talukder et al. 2020). On the contrary, poor farmers cannot use various practices in cultivation due to their financial restrictions (Kumar et al. 2017). Thus, role of poor farmers may be harmful to agricultural sustainability.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>Symbol</th>
<th>Expected sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per capita net state domestic product at factor cost (at current prices)</td>
<td>Rs</td>
<td>PCNSDP</td>
<td>Positive</td>
</tr>
<tr>
<td>Credit Deposit Ratio (GDP) of scheduled commercial banks according to place of utilization</td>
<td>%</td>
<td>CDR</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of credit to agriculture by scheduled commercial banks with gross sown area</td>
<td>Rs/Ha</td>
<td>CASCB/GSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of agriculture GDP with gross sown area</td>
<td>Rs/Ha</td>
<td>AGDPGSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of gross irrigated area with gross sown area</td>
<td>Ratio</td>
<td>GIA/GSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of net irrigated area with net sown area</td>
<td>Ratio</td>
<td>NIA/NSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Average size of holdings</td>
<td>Ha/Holding</td>
<td>ASLH</td>
<td>Positive</td>
</tr>
<tr>
<td>Total food-grain yield</td>
<td>Kg/ha</td>
<td>TFGY</td>
<td>Positive</td>
</tr>
<tr>
<td>Total oilseeds yield (nine crops)</td>
<td>Kg/ha</td>
<td>TOSY</td>
<td>Positive</td>
</tr>
<tr>
<td>Food-grain area as % of gross sown area</td>
<td>%</td>
<td>FGAPGSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Oilseeds area as % of gross sown area</td>
<td>Number</td>
<td>OASPGSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of rural literate population with gross sown area</td>
<td>Number</td>
<td>RLP/GSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of rural poor population with gross sown area</td>
<td>Number</td>
<td>RPPGSA</td>
<td>Negative</td>
</tr>
</tbody>
</table>
Social Equity Index (SEI)

Social development is a multidimensional concept, and it may not be defined by a specific variable (Singh et al. 2019). Human capital and communication among men and women increase as social equity increases (Gaetano 2010). Thus, social equity improves as an increase in factors related to social development (Zhen and Routray 2003). Previous studies developed SEI to examine the ASI in different countries (Hatai and Sen 2008; Gaetano 2010; Sharma and Shardendu 2011; Ghabru et al. 2017; Kareemulla et al. 2017; Fallah-Alipour et al. 2018). In this study, SEI was considered as a function of per capita availability of food-grain and milk production, literacy rate, female literacy rate, gender ratio, birth rate, infant mortality rate, road length per 1000-person, Gini coefficient of distribution of consumption (rural area) and per capita expenditure on social sector. SEI was estimated as a linear sum of CZS of all related variables that are multiplied by an assigned weight and described as:

\[
(SEI)_{st} = W_1(CZS_{PCAFGP})_{st} + W_2(CZS_{PCAMP})_{st} + W_3(CZS_{TLR})_{st} + W_4(CZS_{FLRRU})_{st} + W_5(CZS_{GenRat})_{st} + W_6(CZS_{BRMU})_{st} + W_7(CZS_{IMR})_{st} + W_8(CZS_{RLPP})_{st} + W_9(CZS_{GCDCRA})_{st} + W_{10}(CZS_{PCESS})
\]

(7)

Here, \( W_1, \ldots, W_{10} \) are the allocated weightages and CZS is Composite Z-Score of associated variables and SEI is Social Equity Index in equation (7). A brief explanation of variables is given in Table 2.

Per capita availability of food-grain and milk production significantly contributes to increasing social equity (Zhen and Routray 2003; Singh and Hiremath 2010; Ghabru et al. 2017; Singh and Issac 2018). These variables are helpful to increase food security, human health and social equity. Education level is a vibrant determinant to increase social equity and agricultural sustainability (Latruffe et al. 2016; Kareemulla et al. 2017; Fallah-Alipour et al. 2018). Female literacy measures the overall performance of women’s empowerment (Hatai and Sen 2008; Ghabru et al. 2017). It is also helpful for population stabilization and maintaining social equity (Singh and Issac 2018). Gender equality indicates social equity and women’s development (Gaetano 2010; Latruffe et al. 2016). As birth rate has a significant impact on economic development, urbanization, social structure and religion. Thus, it may be a useful determinant of social equity (Singh and Issac 2018). Infant mortality rate infers the overall performance of health security of women and impact of medical facilities on social security (Hensen 1996; Hatai and Sen 2008; Latruffe et al. 2016; Ghabru et al. 2017; Singh and Issac 2018). Road connectivity measures the progress of infrastructural development and it makes easy transportation of people. Thus, it is a significant contribution towards social development (Hatai and Sen 2008; Kumar et al. 2017). Equal distribution of income effectively maintains social equality (Zhen and Routray 2003; Kumar et al. 2017). Public expenditure on social sector is also helpful to increase social equity (Talukder et al. 2020). Therefore, the aforementioned variables were used to develop SEI in this study.

Ecological Security Index (ESI)

Ecological security is helpful to develop a natural resource-based economy (Ghabru et al. 2017). It maintains the land use pattern, biodiversity, forest area, groundwater, soil fertility and quality, and air quality (Fallah-Alipour et al. 2018). Accordingly, it contributes to increasing agricultural sustainability. Water availability and soil fertility are important determinants of agricultural sustainability (Zhen and Routray 2003). Biodiversity conservation and environmental protection are essential to increase agricultural sustainability (Mili and Martinez-Vega 2019). Hence, ecological security may not be evaluated by a single activity. Singh et al. (2019) created Environmental Sustainability Index (EnSI) to assess the environmental performance across countries. Rostami and Mohammadi (2017) and Mili and Martinez-Vega (2019) generated ESI to assess the performance of agricultural sustainability. Hence, in this study, ESI was formulated as a composition of the ratio of forest area with the gross sown area, a ratio of permanent pasture and grazing lands with the net sown area, the ratio of land not available for cultivation with the gross sown area, cropping intensity, fertilizer consumption/hectare land, population density, population growth, percentage population living in an urban area and annual average precipitation. SEI was estimated as a linear sum of CZS of all associated variables that are multiplied by an assigned weight and explained as:

\[
(ESI)_{st} = W_1(CZS_{RFAGSA})_{st} + W_2(CZS_{RPPGLNSA})_{st} + W_3(CZS_{RLNACGSA})_{st} + W_4(CZS_{CroInt})_{st} + W_5(CZS_{FCPHL})_{st} + W_6(CZS_{PopDen})_{st} + W_7(CZS_{FGR})_{st} + W_8(CZS_{UR})_{st} + W_9(CZS_{AAPCP})_{st}
\]

(8)

Here, ESI is Ecological Security Index; \( W_1, \ldots, W_9 \) are the allocated weightages of corresponding variables; and CZS is Composite Z-Score of associated variables in equation (8). The explanation of other variables is given in Table 3.

Forest area and permanent pasture and grazing land are essential to sustain the environmental quality (Ghabru et al. 2017). Also, forest area absorbs CO₂ emissions from various production sources and it is helpful to maintain air quality and ecological services. Thus, these variables have a positive impact on agricultural sustainability. Therefore, the ratio of forest area with the gross sown area and the ratio of permanent pasture and grazing lands with the net sown area were considered to estimate the ESI (Singh and Issac 2018; Singh et al. 2019). Not cultivated land for farming has a negative implication on agricultural sustainability. Thus, ratio of land not available for cultivation with gross sown area was used to develop ESI (Mili and Martinez-Vega 2019). Cropping intensity measures a particular land’s use for growing various crops in a year. Production of food-grain and commercial crops and farmer’s income increase as cropping intensity increases. Consequently, it positively impacts agricultural sustainability (Kumar et al. 2017; Singh and Issac 2018). The application of fertilizer and pesticides in cultivation may be caused to increase in environmental degradation (Lampridi et al. 2019). Thus, agricultural sustainability may be adversely affected due to the extensive use of fertilizer in the agricultural sector (Singh et al. 2019).
The estimates showed a significant variation in value of EEI lies between 0.17 to 0.82 across Indian states. Economic efficiency, Himachal Pradesh, Bihar and Assam have the 15th, 16th and 17th positions, respectively, regarding economic efficiency. The EEI values for Tamil Nadu, Gujarat, West Bengal and Andhra Pradesh were between 0.30 to 0.40. Thus, these states have a better position in irrigated area, yield of food-grain and oilseed crops, literate population, cropping intensity, per capita net state domestic product, and credit facilities for the agricultural sector used to develop EEI. Therefore, Punjab and Haryana were in best position in agricultural sustainability. EEI values for Kerala, Rajasthan, Karnataka, Uttar Pradesh, Madhya Pradesh, Maharashtra, Jammu & Kashmir were between 0.20 to 0.30. Thus, these states have a relatively poor position regarding economic efficiency. In terms of economic efficiency, Himachal Pradesh, Bihar and Assam have the 15th, 16th and 17th positions. Furthermore, the value of EEI lies between 0.17 to 0.82 across Indian states. Thus, the estimates showed a significant variation in economic efficiency across Indian states due to high diversity in economic development-related variables.

## RESULTS AND DISCUSSION

### Presentation of Indian States in economic efficiency

Mean values of EEI during 1990-2017 are given in Figure 1. It revealed that Haryana and Punjab were 1st and 2nd in position, respectively, regarding economic efficiency among the 17 Indian states. These states have a better position in irrigated area, yield of food-grain and oilseed crops, literate population, cropping intensity, per capita net state domestic product, and credit facilities for the agricultural sector used to develop EEI. Therefore, Punjab and Haryana were in best position in agricultural sustainability. EEI values for Tamil Nadu, Gujarat, West Bengal and Andhra Pradesh were between 0.30 to 0.40. Thus, these states have the 3rd, 4th, 5th and 6th positions concerning economic efficiency. The EEI values for Kerala, Rajasthan, Karnataka, Uttar Pradesh, Madhya Pradesh, Maharashtra, Jammu & Kashmir were between 0.20 to 0.30. Thus, these states have a relatively poor position regarding economic efficiency. In terms of economic efficiency, Himachal Pradesh, Bihar and Assam have the 15th, 16th and 17th positions. Furthermore, the value of EEI lies between 0.17 to 0.82 across Indian states. Thus, the estimates showed a significant variation in economic efficiency across Indian states due to high diversity in economic development-related variables.

### Table 2. Explanation of social equity associated variables

<table>
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<th>Indicator</th>
<th>Unit</th>
<th>Symbol</th>
<th>Expected sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per capita availability of food-grain production</td>
<td>Kg/Year</td>
<td>PCAFGP</td>
<td>Positive</td>
</tr>
<tr>
<td>Per capita availability of milk production</td>
<td>Gram/day</td>
<td>PCAMP</td>
<td>Positive</td>
</tr>
<tr>
<td>Total literacy rate (Rural+Urban)</td>
<td>%</td>
<td>TLR</td>
<td>Positive</td>
</tr>
<tr>
<td>Female literacy rate (Rural+Urban)</td>
<td>%</td>
<td>FLRLRU</td>
<td>Positive</td>
</tr>
<tr>
<td>Gender ratio (Female/1000 Males)</td>
<td>Number</td>
<td>GenRRat</td>
<td>Positive</td>
</tr>
<tr>
<td>Birth rate (Rural+Urban) (Per 000 population)</td>
<td>Number</td>
<td>IMR</td>
<td>Negative</td>
</tr>
<tr>
<td>Infant mortality rate (Per 000 live births)</td>
<td>Number</td>
<td>RLPP</td>
<td>Positive</td>
</tr>
<tr>
<td>Road length per 1000 person</td>
<td>Kms/1000</td>
<td>RPLTP</td>
<td>Positive</td>
</tr>
<tr>
<td>Gini coefficient of distribution of consumption</td>
<td>Number</td>
<td>GCDR</td>
<td>Negative</td>
</tr>
<tr>
<td>Per capita expenditure on social sector</td>
<td>Rs</td>
<td>PCESS</td>
<td>Positive</td>
</tr>
</tbody>
</table>

### Table 3. Explanation of ecological security associated variables

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Unit</th>
<th>Symbol</th>
<th>Expected sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of forest area with gross sown area</td>
<td>Ratio</td>
<td>RFAGSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of permanent pasture and grazing lands with net sown area</td>
<td>%</td>
<td>RPPGLNSA</td>
<td>Positive</td>
</tr>
<tr>
<td>Ratio of land not available for cultivation with gross sown area</td>
<td>%</td>
<td>RLNACGSA</td>
<td>Negative</td>
</tr>
<tr>
<td>Cropping intensity</td>
<td>%</td>
<td>CroInt</td>
<td>Positive</td>
</tr>
<tr>
<td>Fertilizer consumption/hectare land (N+P+K)</td>
<td>Kg</td>
<td>FCPHL</td>
<td>Negative</td>
</tr>
<tr>
<td>Population density</td>
<td>Number</td>
<td>PopDen</td>
<td>Negative</td>
</tr>
<tr>
<td>Population growth rate (Rural+Urban)</td>
<td>%</td>
<td>PGR</td>
<td>Negative</td>
</tr>
<tr>
<td>Percentage population living in urban area</td>
<td>%</td>
<td>UR</td>
<td>Negative</td>
</tr>
<tr>
<td>Annual average precipitation</td>
<td>mm</td>
<td>AAPCP</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Moreover, ecosystem services are negatively impacted due to overwhelming population density, population growth and urbanization. Therefore, these factors increase the additional pressure on ecological services (Fallah-Alipour et al. 2018; Singh et al. 2019). Precipitation is a natural resource and it has a crucial contribution to the increase and sustenance of agricultural production. Hence, variables, as mentioned earlier, were used to estimate ESI in this study.

### Empirical model on the association of ASI with climatic factors

Previous studies could not examine the impact of climatic factors on agricultural sustainability. Hence, this study examines the influence of climatic factors (i.e., AAMaxT and AAMinT and AARF) on ASI. For the investigation above, the present study adopted model from studies of Kumar et al. (2017), Singh and Issac (2018), Singh et al. (2019), which have used estimated indexes as dependent and independent variables. Therefore, linear regression model was used to estimate the regression coefficient of explanatory variables with ASI and specified as:

\[
\text{ASI}_t = \alpha_0 + \alpha_1 \times (\text{TTF})_t + \alpha_2 \times (\text{EEI})_t + \alpha_3 \times (\text{SFD})_t + \alpha_4 \times (\text{ESI})_t + \alpha_5 \times (\text{AAMaxT})_t + \alpha_6 \times (\text{AAMinT})_t + \alpha_7 \times (\text{AARF})_t + \epsilon_t \tag{9}
\]

Here, ASI is the Agricultural Sustainability Index; EEI is Economic Efficiency Index; SFD is Social Equity Index; AAMaxT and AAMinT are the Annual Average Maximum And Minimum Temperature, respectively; AARF is the Actual Annual Rainfall; TTF is time trend factor that was used to capture the influence of technological advancement on agricultural sustainability (Kumar et al. 2017); \( \alpha_0 \) is the constant coefficient; \( \alpha_1, ..., \alpha_7 \) are the regression coefficients of associated independent variables; \( \epsilon_t \) is the error term; and \( t \) is period in equation (9). Log-linear and non-linear regression models were also used to check the consistency of regression coefficients.
Performance of Indian states in social equity

A comparison of Indian states based on estimated mean values of a SEI during 1990-2017 is given in Figure 2. Kerala and Himachal Pradesh have shown 1st and 2nd positions in social equity. As values of SEI was an integrated index of various variables which have a significant association with social development. Kerala and Himachal Pradesh have high literacy rates, female literacy rates, gender ratios and per capita expenditure on the social sector. Thus, both the states have a better position in social equity among the Indian states. On the other hand, per capita availability of food-grain and milk production was higher in Punjab and Haryana than in other Indian states. Thus, Punjab and Haryana have the 3rd and 4th positions in social equity among the 17 Indian states. Maharashtra, Tamil Nadu, Gujarat, Assam, Rajasthan, Odisha, West Bengal, Jammu & Kashmir, Madhya Pradesh and Andhra Pradesh have a relatively poor position in social equity. Bihar and Uttar Pradesh seemed to worsen their position in social equity among the Indian states. Bihar and Uttar Pradesh have low per capita availability of food-grain production, per expenditure on social sector and milk production, high infant mortality rate and inequality in consumption pattern. Thus, these states could not improve their position in social equity. Furthermore, high variation in social equity was experienced due to significant diversity in social development-related activities in Indian states.

Performance of Indian states in ecological security

The cross comparative of Indian states in ecological security based on mean values of ESI during 1990-2017 is given in Figure 3. It infers that Himachal Pradesh was in the best position in ecological security among the 17 Indian states. The values of ESI lie between 0.72-0.26 across Indian states. It indicates a high variation in ecological security across the Indian states. As the value of ESI was an integrated index of share of forest area, permanent pasture and grazing land not available for cultivation in the gross sown area; cropping intensity; fertilizer consumption; population density; population growth; urbanization and annual average precipitation. Himachal Pradesh has shown a better position in most factors positively associated with ecological security. It means the state has maintained their significant position in ecological security. Odisha ranked 2nd in ecological security due to its better forest area, permanent pasture and grazing lands and annual precipitation. Gujarat, Tamil Nadu and Haryana have ranked 15th, 16th and 17th in ecological security. Thus, these states could not improve their position in ecological security. The ESI values lie between 0.4-0.5 for Assam, Jammu & Kashmir, Kerala, Madhya Pradesh and West Bengal. These states were in a moderate position in ecological security among the Indian states.
Figure 2. Comparison of Indian states based on Social Equity Index (SEI)

Figure 3: Comparison of Indian states based on Ecological Security Index (ESI)
Figure 4. Performance of Indian states in agricultural sustainability

Figure 5. Comparison between states based on EEI, SEI, ESI and ASI
Performance of Indian States in agricultural sustainability

The cross-comparison of Indian states in agricultural sustainability as per the estimated mean values of ASI from 1990 to 2017 is given in Figure 4. Cross comparison of states based on EEI, SEI, ESI and ASI is given in Figure 5. The values of ASI lie between 0.25-0.49. It infers that there was high variation in agricultural sustainability across Indian states. Haryana, Himachal Pradesh and Punjab have ranked 1st, 2nd and 3rd position in ASI, respectively. These two states have the better position in most factors which were main determinants of economic efficiency, social equity and ecological security. It means that these states have the appropriate ecosystem to maintain agricultural sustainability. On the other hand, Bihar and Uttar Pradesh have the 17th and 18th ranks in ASI. Thus, both the states could not maintain agricultural sustainability due to several reasons such as extreme poverty, low literacy rate, high pressure of population on agriculture, low coping intensity, high-income inequality, high unemployment rate, low infrastructural development and others.

Validity of ASI, EEI, SEI and ESI

Internal and external validation of an index is essential to increase the unanimity among the researchers and academicians. Thereupon, an estimated index can be used for further empirical investigation. Therefore, Karl-Pearson correlation coefficient of ASI with EEI, SEI, ESI were estimated to check their internal validity. The correlation coefficients of these indexes with climatic factors were assessed to check their external validity. Kumar et al. (2017), Singh and Issac (2018), Singh et al. (2019) have also used a similar technique to identify the internal and external validity of proposed indexes. The correlation coefficient of ASI with EEI, SEI, ESI, AAMaxt and AAMinT were statistically significant at 1% significant level (Table 4). Thus, these indexes have viability and estimates infer that agricultural sustainability increases with economic efficiency, social equity and ecological security. On the other hand, annual maximum and minimum temperatures were negatively associated with agricultural sustainability. Here, climate change seemed to harm agricultural sustainability in India. It was also reported that agricultural sustainability could not be achieved without maintaining economic efficiency, social equity, and ecological security in agricultural sector.

Discussion on empirical results

The empirical results which examine the influence of EEI, SEI, ESI, AAMaxt, AAMinT and AARF on ASI are given in Table 5. The regression coefficient of variables above with ASI was estimated through linear, log-linear and non-linear regression models. Furthermore, the panel correction standard estimation model was effective in reducing the incidence of serial correlation, heteroskedasticity and cross-sectional autocorrelation in panel data investigation (Kumar et al. 2016, 2017; Singh et al. 2019). Thus, this model was considered to estimate the regression coefficient of the aforementioned independent variables with ASI. Mean values of Variance Inflation Factor (VIF) for linear regression and log-linear regression models were 3.21 and 5.36, respectively, indicating the absence of multi-correlation among the explanatory variables in panel data. Furthermore, χ² values under Ramsey RESET test for powers of the fitted values of ASI and the independent variables were statistically significant at 1% significance level. Hence, the functional form of the proposed models was found to be well-defined. A log-linear regression model is reported to have a lower value of Akaike Information Criterion (AIC) and Bayesian Information Criteria (BIC) as compared to linear and non-linear regression models (Kumar et al. 2017; Singh and Issac 2018; Singh et al. 2019). Hence, the explanation of results based on this model was included in this study.

The R² value was 0.94, showing that 94% variation in agricultural sustainability depends on technological advancement, economic efficiency, social equity, ecological security, and climatic factors. The regression coefficient of the time trend factor with agricultural sustainability was appeared positive and statistically significant, which indicated that the use of technological advancement in farming would be useful to increase crop production and agricultural sustainability. The regression coefficient of EEI, SEI and ESI with ASI seemed positive and statistically significant. The estimates showed that agricultural sustainability improved with increased economic efficiency, social equity and ecological security. On the other hand, the AAMaxT negatively influenced ASI. Thus, it was seen that agricultural sustainability might decline with an increase in AAMaxT. While agricultural sustainability was positively associated with AAMinT and AARF in India.

Table 4. Correlation coefficient of ASI with its components and climatic factors

<table>
<thead>
<tr>
<th></th>
<th>ASI</th>
<th>EEI</th>
<th>SEI</th>
<th>ESI</th>
<th>AAMaxT</th>
<th>AAMinT</th>
<th>AARF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASI</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEI</td>
<td>0.563**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEI</td>
<td>0.799**</td>
<td>0.199**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESI</td>
<td>0.334**</td>
<td>-0.510**</td>
<td>0.348**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAMaxT</td>
<td>-0.358**</td>
<td>0.145**</td>
<td>-0.293**</td>
<td>-0.601**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAMinT</td>
<td>-0.338**</td>
<td>0.017</td>
<td>-0.182**</td>
<td>-0.482**</td>
<td>0.895**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>AARF</td>
<td>0.016</td>
<td>-0.212**</td>
<td>0.112**</td>
<td>0.230**</td>
<td>-0.042</td>
<td>0.123**</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: **: Correlation coefficient is statistically significant at the 0.01 level. ASI: Agricultural Sustainability Index; EEI: Economic Efficiency Index; SEI: Social Equity Index; ESI: Ecological Security Index; AAMaxT: Annual Average Maximum Temperature; AAMinT: Annual Average Minimum Temperature; AARF: Annual Actual Rainfall
The estimates suggested that agricultural sustainability to improve economic development, social development and ecological security may be considered useful to states. Thus, economic development, social development, and ecological security factors may be considered useful to understand the relationship with agricultural sustainability. Per capita net domestic product, credit to agriculture sector by a commercial bank, and ratio of agriculture GDP with the gross sown area, share of irrigated area in gross area sown, a ratio of a net irrigated area with the net sown area and the average size of landholding, a yield of food-grain and oilseed crops, a cropped area under food-grain and oilseed crops, and the ratio of the rural literate population with the gross sown area were positively associated with EEI. Thus, these variables must be considered in other policy formulation to maintain an increase in economic efficiency, social equity, and rainfall to a certain extent. Agricultural sustainability showed a hilly-shaped relationship with AAMaxT and AAMinT. The estimates provided evidence that annual maximum temperature and minimum temperature have a positive implication on agricultural sustainability up to a certain level, thereafter, both the variables will harm it. Finally, ecological security had a linear relationship with agricultural sustainability, indicating improved agricultural sustainability with increased ecological security.

### Conclusion and policy suggestions

The descriptive results showed that ASI was positively associated with the EEI, SEI and ESI. Haryana and Himachal Pradesh had the 1st and 2nd ranks in ASI. On the other hand, Bihar, Uttar Pradesh and Andhra Pradesh had the 17th, 16th and 15th ranks, respectively, in ASI. Hence, the agriculture sector was in a vulnerable position in these states. Thus, economic development, social development, and ecological security factors may be considered useful to improve agricultural sustainability in India. Consequently, they can apply several inputs to increase their profitability in the agricultural sector. Further, it is suggested that Assam, Bihar, Himachal Pradesh, Odisha, Jammu & Kashmir, Maharashtra, Madhya Pradesh, Uttar Pradesh, Karnataka, Rajasthan, Kerala, Andhra Pradesh, West Bengal and Gujarat should focus on aforesaid activities to improve their economic efficiency.

### Table 5. Association of ASI with its components and climatic factors

<table>
<thead>
<tr>
<th>Name of models</th>
<th>Linear regression</th>
<th>Log-linear regression</th>
<th>Non-linear regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTF</td>
<td>0.0001</td>
<td>0.836</td>
<td>0.0005</td>
</tr>
<tr>
<td>ESI</td>
<td>0.3284</td>
<td>0.000</td>
<td>0.3389</td>
</tr>
<tr>
<td>(EES)^2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(EES)^2</td>
<td>0.3430</td>
<td>0.000</td>
<td>0.3581</td>
</tr>
<tr>
<td>(EES)^2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ESI</td>
<td>0.3217</td>
<td>0.000</td>
<td>0.3548</td>
</tr>
<tr>
<td>(EES)^2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AAMaxT</td>
<td>-0.0001</td>
<td>0.811</td>
<td>-0.1414</td>
</tr>
<tr>
<td>(AAMaxT)^2</td>
<td>0.0001</td>
<td>0.694</td>
<td>0.0060</td>
</tr>
<tr>
<td>AAMinT</td>
<td>0.0001</td>
<td>0.570</td>
<td>0.0060</td>
</tr>
<tr>
<td>(AAMinT)^2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AARF</td>
<td>0.0000</td>
<td>0.007</td>
<td>0.0060</td>
</tr>
<tr>
<td>(AARF)^2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Con. Coef.</td>
<td>-0.2870</td>
<td>0.001</td>
<td>-0.4337</td>
</tr>
</tbody>
</table>

Note: VIF: Variance Inflation Factor; AIC: Akaike Information Criterion; BIC: Bayesian Information Criteria; Con. Coef.: Constant Coefficient

Government should integrate development policies in economic and social development and ecological security to increase agricultural sustainability in India.

Also, the values of EEI lie between 0.17-0.82, thus, there exists a significant variation in economic efficiency among the 17 Indian states. Haryana and Punjab have shown the 1st and 2nd positions in economic efficiency. Therefore, these states could create appropriate infrastructure to be in the best position in economic efficiency.

Per capita net domestic product, credit to agriculture sector by a commercial bank, and ratio of agriculture GDP with the gross sown area, share of irrigated area in gross area sown, a ratio of a net irrigated area with the net sown area, the average size of landholding, a yield of food-grain and oilseed crops, a cropped area under food-grain crops and the ratio of the rural literate population with the gross sown area were positively associated with EEI. Thus, these variables must be considered in other policy formulation to maintain economic development in India. Cash crop farming provides a better economic return to farmers than food-grain farming. Hence, a farming community should grow commercial crops to increase their economic capacity.
The values of SEI lie between 0.241-0.538 across Indian states. Thus, Indian states have high diversity in social equity due to variation in social development associated variables. In social equity, Kerala, Himachal Pradesh and Karnataka have shown the 1st, 2nd and 3rd ranks, respectively. Thus, these states have better performance in social equity among the 17 Indian states. On the other hand, Uttar Pradesh and Bihar were in the lowest position in social equity. SEI was positively correlated with per capita food-grain availability, per capita availability of milk production, total literacy rate, female literacy rate, road length per thousand population, and expenditure on the social sector. Thus, these variables were found to be the most crucial determinants of social equity. Furthermore, social equity decreases with increasing birth rate and infant mortality rate. Uttar Pradesh, Bihar, Andhra Pradesh, Madhya Pradesh, Jammu & Kashmir, West Bengal, Odisha, Rajasthan Assam, Gujarat and Tamil Nadu are suggested to include aforesaid variables in policy formulation to improve their position in terms of social equity. Also, the Indian Government should provide better medical facilities to control infant mortality to increase social development.

Moreover, the values of ESI lies between 0.26-0.72 across Indian states, which proves that these states have high diversity in ecological security. The high diversity in ecological security exists due to variation in available natural resources and ecological services in Indian states. In ESI, Himachal Pradesh and Odisha have shown the 17th and 16th ranks. Therefore, both the states performed relatively better in ecological security among the 17 states. Haryana, Tamil Nadu and Gujarat had the 17th, 16th and 15th positions, respectively, in ecological security among the Indian states. The ratio of forest area with the gross sown area, permanent pasture land with the gross sown area, cropping intensity and annual average precipitation was positively associated with ESI. Forest area seemed to be the most important factor to mitigate the several negative impacts of socio-economic activities and climate change on ecological services. Forest area also works as an ecosystem-adaptation-based approach to mitigate the negative consequences of climate change in the agricultural sector. Thus, the Government should implement a conducive policy to protect the forest area from increasing agricultural sustainability in India. Furthermore, it is also desirable to increase cropping intensity using better irrigation facilities, green technologies, green fertilizer, conserve traditional crop varieties and develop high yielding and climate change resilient varieties of seeds in the agricultural sector to increase ecological security in India. However, the negative impact has been observed between ecological security with a ratio of land not used for cultivation with the gross sown area, fertilizer consumption per hectare land, population density, population growth and urbanization. Extensive use of fertilizer in cultivation may cause to increase GHGs emissions in the atmosphere, subsequently, it may be responsible for further escalation of climate change and to improve environmental degradation. Thus, a farming community should avoid extensive fertilizer use to maintain ecological security. Subsequently, the optimum quantity of fertilizer in cultivation will be helpful to increase agricultural sustainability. Application of green fertilizer and green and appropriate technology in cultivation may be helpful to increase the ecological security and agricultural sustainability in India. Furthermore, India should control population density, population growth and urbanization to protect available ecosystem services to increase agricultural sustainability. Overwhelming industrialization is also a main source of GHGs emissions in the atmosphere which may be caused to increase high possibility of climate change and environmental degradation. Therefore, Indian Government should focus on green entrepreneurship and green technology to sustain ecological services and sustainable agricultural development.

Empirical results infer that technological advancement in cultivation may be helpful to increase agricultural sustainability. Hence, farmers should apply agricultural and green technology to avoid the risk of climate change in cultivation. Furthermore, it was found that economic efficiency, social equity and climatic factors have a non-linear association with agricultural sustainability. The estimates also infer that economic efficiency, social equity and ecological security have positive implications on agricultural sustainability. Thus, policymakers should centralize an integrated policy to increase economic development, social development and ecological security. Climatic factors such as AAMaxT and AAMinT and AARF significantly influence agricultural sustainability. The impact of maximum temperature on agricultural sustainability was seemed negative and statistically significant. Thus, agricultural sustainability was adversely affected due to an increase in maximum temperature in India. Hence, Indian farmers should apply adaptation strategies to avoid the negative impact of climate shocks in crop farming. For this, India needs to discover alternative options such as technology, heat tolerance crops, irrigation facilities, mixed-cropping pattern, agroforestry and other practices to mitigate the negative consequences of climate change in agriculture. It was also found that economic efficiency, social equity and climatic factors have a non-linear association with agricultural sustainability. Existing researchers can also examine the implications of farmer’s adaptation strategies and mitigation approaches to climate change and technological advancement in the agricultural sector in a further study using farm-level information.

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