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

AJAY KUMAR SINGH[1,♥], SANJEEV KUMAR[1], BHIM JYOTI[2]
[1]School of Liberal Arts & Management, DIT University. Mussoorie, Diversion Road, Makka Wala, Uttarakhand 248009, India.
Tel./Fax. +91-90846-72084, ♥email: a.k.seeku@gmail.com
[2]Department of Seed Science and Technology, VCSG, Uttarakhand University of Horticulture and Forestry. Ranichauri, Tehri Garhwal, Uttarakhand 249199, India

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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 the Agricultural Sustainability Index (ASI) in 17 Indian states during 1990-2017. The Composite Z-Score method integrated 32 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 models 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 help 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's Gross Domestic Product (GDP) and gross irrigated area with the gross sown area, landholding size, 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. The total literacy rate, female literacy rate, and rural literate population were the most crucial factors in improving 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; EDI: Economic Development Index; EEI: Economic Efficiency Index; EnSI: Environmental Sustainability Index; GoI: Government of India; GHGs: Greenhouse Gases; GDP: Gross Domestic Product; IMD: Indian Metrological 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 the sole sector to meet the food demand of people, provide raw materials to industries, create employment for agricultural laborers, and gives fodder to livestock. Moreover, 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 urgent 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, and 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 the economic accessibility of farmers (Rostami and Mohammadi 2017). Moreover, it maintains economic viability and social welfare by sustaining the quality of natural resources (Hensen 1996). Finally, 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 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-Alipour et al. (2018) defined agricultural sustainability as protecting the environment and improving agricultural production and human well-being. Furthermore, several studies have claimed that agricultural sustainability includes socio-economic 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 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, and biodiversity), contributing to 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. Several studies have assessed the influence of various activities on the agricultural sector in India using primary and secondary data at the district, state, region, and country levels. 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 the 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). The 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 the 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. The credit Deposit Ratio (CDR) of scheduled commercial banks, credit disbursed to agriculture by scheduled commercial banks, and agriculture Gross Domestic Product (GDP) was taken from the 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 and infant mortality rates were taken from the 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 the 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 database and Indian Metrological Department (IMD), GoI. Data for a few variables (e.g., literacy rate, female literacy rate, birth rate, urbanization, population density, the average size of land holding, rural literate person, rural poor people) were not available in the time series. Thus, interpolation and extrapolation methods were used to compute the median 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-Alipour 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 the World Bank, United Nations, and Organization for Economic Cooperation 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 (Qiu et al. 2007; Hatai and Sen 2008; Gaetano 2010; Sharma and Shardendu 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, principal components, and factor component analysis, including 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 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:

$$CZS_{is} = \{[X_{is} - Min(X_{is})]/[Max(X_{is}) - Min(X_{is})]\} \quad (1)$$

Here, CZS is the Composite Z-Score for the i^{th} variable, and *s* is cross-sectional states. X_{is} is the actual value; $Min(X_{is})$ is the minimum value; $Max(X_{is})$ is the 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, then the CZS (Rostami and Mohammadi 2017) was estimated as follows:

$$CZS_{is} = \{[X_{is} - Max(X_{is})]/[Min(X_{is}) - Max(X_{is})]\} \quad (2)$$

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

Estimation of weights for arbitrary variable

The Weightage technique is useful for dividing 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:

$$Wi = \frac{K}{\sqrt{Var(CZS)}} \quad (3)$$

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

Here, $K = \frac{1}{\left\{\sum_{i=1}^{m}\left(\frac{1}{\sqrt{Var(CZS)}}\right)\right\}}$ (4)

Aggregate sum

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

Development of the 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 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 Shardendu 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:

$$(ASI)_{st} = \{(EEI)_{st} + SEI)_{st} + (ESI)_{st}\}/3 \quad (5)$$

Here, ASI is Agricultural Sustainability Index, EEI is Economic Efficiency Index, SEI is the 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 has a significant association with several country activities (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 the agricultural sector (Gaetano 2010). Thus, economic development helps increase the agricultural production system's productivity, profitability, and stability (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:

$$
\begin{aligned}
(EEI)_{st} =\ & W_1\times(CZS\_PCNSDP)_{st} + W_2\times(CZS\_CDR)_{st} \\
& + W_3\times(CZS\_CASCB/GSA)_{st} + W_4\times (CZS\_AGDPGSA)_{st} \\
& + W_5\times(CZS\_GIA/GSA)_{st} + W_6\times(CZS\_NIA/NSA)_{st} \\
& + W_7\times(CZS\_ASLH)_{st} + W_8 \times(CZS\_TFGY)_{st} + W_9\times(CZS\_TOSY)_{st} \\
& + W_{10}\times(CZS\_FGAPGSA)_{st} + W_{11}\times(CZS\_OASPGSA)_{st} \\
& + W_{12}\times(CZS\_RLP/GSA)_{st} + W_{13}\times(CZS\_RPPGSA)_{st} \qquad (6)
\end{aligned}
$$

Here, W_1 …. W_{13} are the assigned weightages, and CZS is the Composite Z-Score of associated variables in equation (6). A brief of economic efficiency-associated variables has been given in Table 1.

Per capita income is a vital indicator of national development and prosperity (Hatai and Sen, 2008). It also maintains overall livelihood security and agricultural sustainability. Thus, per capita net state domestic product was considered to estimate EEI (Singh and Issac 2018). The CDR helps increase money flow and financial stability in the domestic market and 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 the gross irrigated area with the gross sown area and the net irrigated area with the net sown area was used to develop EEI (Ghabru et al. 2017). Farm management practices and technologies can be used in large landholding. Thus, landholding size is 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 to agricultural sustainability (Kumar et al. 2017; Mili and Martínez-Vega 2019). Though India is rich in traditional knowledge of 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, the role of poor farmers may be harmful to agricultural sustainability.

Table 1. Explanation of economic efficiency associated variables

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

Social Equity Index (SEI)

Social development is a multidimensional concept that 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 the social sector. The SEI was estimated as a linear sum of CZS of all related variables multiplied by an assigned weight and described as:

$$(SEI)_{st} = W_1 \times (CZS\_PCAFGP)_{st} + W_2 \times (CZS\_PCAMP)_{st} + W_3 \times (CZS\_TLR)_{st} + W_4 \times (CZS\_FLRRU)_{st} + W_5 \times (CZS\_GenRat)_{st} + W_6 \times (CZS\_BRRU)_{st} + W_7 \times (CZS\_IMR)_{st} + W_8 \times (CZS\_RLPTP)_{st} + W_9 \times (CZS\_GCDCRA)_{st} + W_{10} \times (CZS\_PCESS) \quad (7)$$

Here, W_1 …. W_{10} are the allocated weightages, CZS is the Composite Z-Score of associated variables, and SEI is the Social Equity Index in equation (7). A brief explanation of the 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 help increase food security, human health, and social equity. Moreover, education level is a vibrant determinant of increasing social equity and agricultural sustainability (Latruffe et al. 2016; Kareemulla et al. 2017; Fallah-Alipour et al. 2018). Furthermore, 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). For example, the birth rate significantly impacts 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 women's overall performance and health security and the 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, making transportation easy for people. Thus, it significantly contributes to social development (Hatai and Sen 2008; Kumar et al. 2017). Equal income distribution effectively maintains social equality (Zhen and Routray 2003; Kumar et al. 2017). Public expenditure on the social sector is also helpful in increasing social equity (Talukder et al. 2020). Therefore, the abovementioned variables were used to develop SEI in this study.

Ecological Security Index (ESI)

Ecological security helps 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 Martínez-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 Martínez-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. The ESI was estimated as a linear sum of CZS of all associated variables multiplied by an assigned weight and explained as:

$$(ESI)_{st} = W_1 \times (CZS\_RFAGSA)_{st} + W_2 \times (CZS\_RPPGLNSA)_{st} + W_3 \times (CZS\_RLNACGSA)_{st} + W_4 \times (CZS\_CroInt)_{st} + W_5 \times (CZS\_FCPHL)_{st} + W_6 \times (CZS\_PopDen)_{st} + W_7 \times (CZS\_PGR)_{st} + W_8 \times (CZS\_UR)_{st} + W_9 \times (CZS\_AAPCP)_{st} \quad (8)$$

Here, ESI is Ecological Security Index; W_1 …. 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 areas, permanent pastures, and grazing land are essential to sustain environmental quality (Ghabru et al. 2017). Also, forest area absorbs CO_2 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, the ratio of land unavailable for cultivation with the gross sown area was used to develop ESI (Mili and Martínez-Vega 2019). Cropping intensity measures a particular land's use for growing various crops in a year. The production of food grain and commercial crops and farmers' 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).

Table 2. Explanation of social equity associated variables

Indicator	Unit	Symbol	Expected sign
Per capita availability of food-grain production	Kg./Year	*PCAFGP*	Positive
Per capita availability of milk production	Gram/day	*PCAMP*	Positive
Total literacy rate (Rural+Urban)	%	*TLR*	Positive
Female literacy rate (Rural+Urban)	%	*FLRRU*	Positive
Gender ratio (Female/1000 Males)	Number	*GenRat*	Positive
Birth rate (Rural+Urban) (Per '000 population)	Number	*BRRU*	Positive
Infant mortality rate (Per '000 live births)	Number	*IMR*	Negative
Road length per 1000 person	Km/1000 person	*RLPTP*	Positive
Gini coefficient of distribution of consumption (Rural+Urban)	Number	*GCDCRA*	Negative
Per capita expenditure on social sector (Rural+Urban)	Rs	*PCESS*	Positive

Table 3. Explanation of ecological security associated variables

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

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). On the other hand, precipitation is a natural resource that contributes to increasing and sustaining agricultural production. Hence, as mentioned earlier, this study used those variables to estimate ESI.

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, AAMinT, and AARF) on ASI. For the investigation above, the present study adopted a model from studies of Kumar et al. (2017), Singh and Issac (2018), and Singh et al. (2019), which used estimated indexes as dependent and independent variables. Therefore, a linear regression model was used to estimate the regression coefficient of explanatory variables with ASI and specified as:

$$(ASI)_{st} = \alpha_0 + \alpha_1 (TTF)_{st} + \alpha_2 (EEI)_{st} + \alpha_3 (SEI)_{st} + \alpha_4 (ESI)_{st} + \alpha_5 (AAMaxT)_{st} + \alpha_6 (AAMinT)_{st} + \alpha_6 (AARF)_{st} + \zeta_{st} \quad (9)$$

Here, ASI is the Agricultural Sustainability Index, EEI is Economic Efficiency Index, SEI is Social Equity Index; AAMaxT and AAMinT are the Annual Average Maximum And Minimum Temperature, respectively; AARF is the Actual Annual Rainfall; TTF is the time trend factor that was used to capture the influence of technological advancement on agricultural sustainability (Kumar et al. 2017); α_0 is the constant coefficient; $\alpha_1, \ldots, \alpha_6$ are the regression coefficients of associated independent variables; ζ_{st} is the error term; and *s* is cross-sectional states; *t* is period in equation (9). Log-linear and non-linear regression models were also used to check the consistency of regression coefficients.

RESULTS AND DISCUSSION

Presentation of Indian States in economic efficiency

The mean values of EEI during 1990-2017 are given in Figure 1. It revealed that Haryana and Punjab were 1st and 2nd in the position, respectively, regarding economic efficiency among the 17 Indian states. These states have a better position in irrigated areas, 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 the best position for 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. Regarding 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 the high diversity in economic development-related variables.

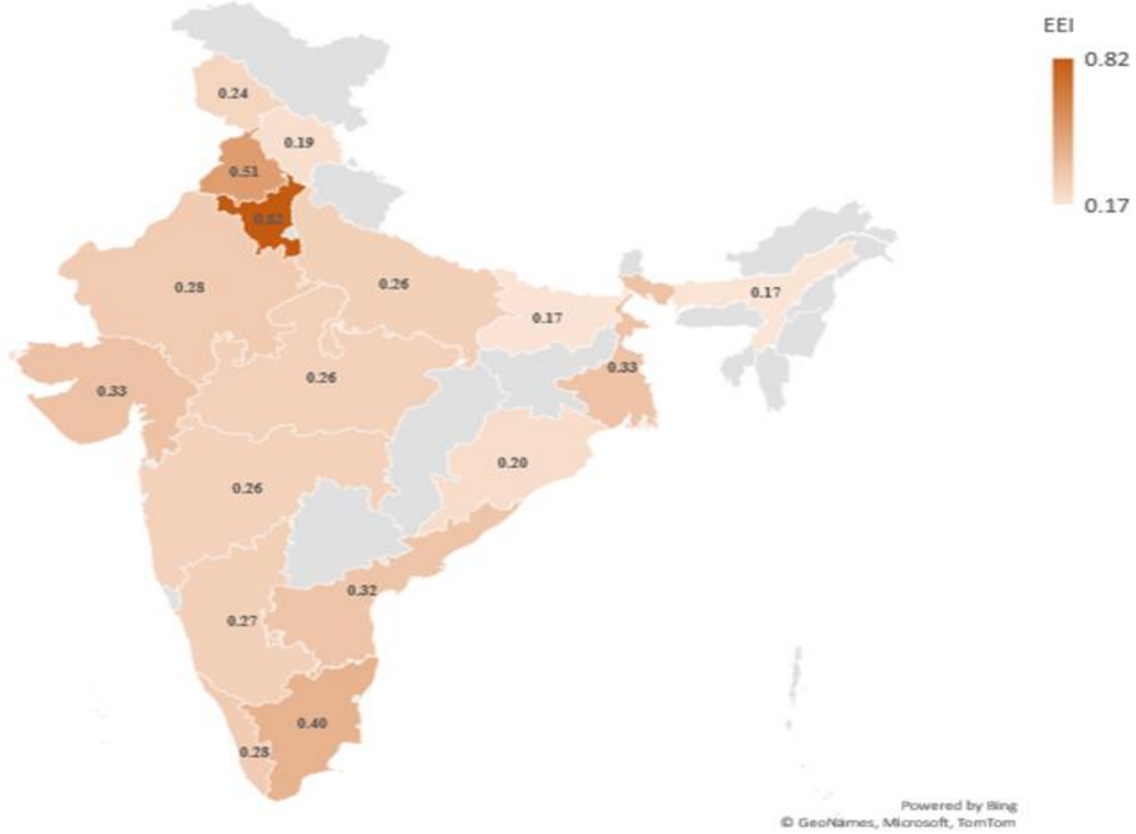

Figure 1. Comparison of Indian states as per the Economic Efficiency Index (EEI)

Performance of Indian states in social equity

A comparison of Indian states based on estimated mean values of an SEI during 1990-2017 is given in Figure 2. Kerala and Himachal Pradesh have shown 1st and 2nd positions in social equity. Moreover, the values of SEI were 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 in the social sector. Thus, both 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. That means the state has maintained its significant position in ecological security. On the other hand, 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.

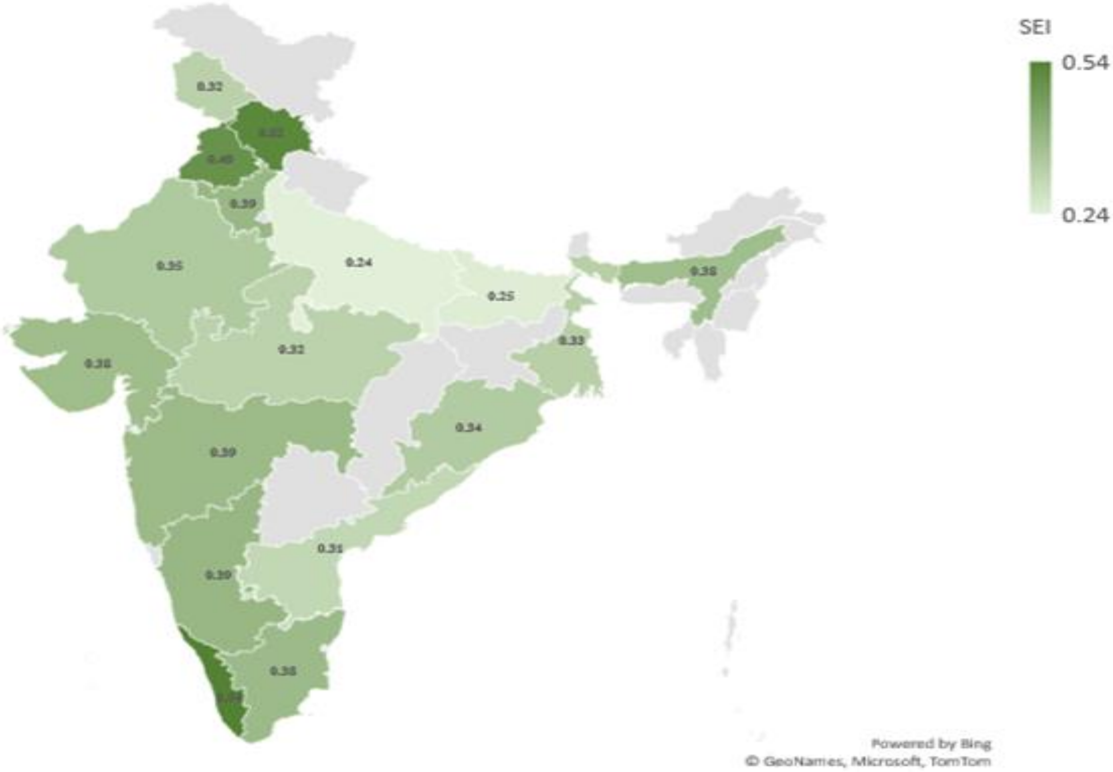

Figure 2. Comparison of Indian states based on the Social Equity Index (SEI)

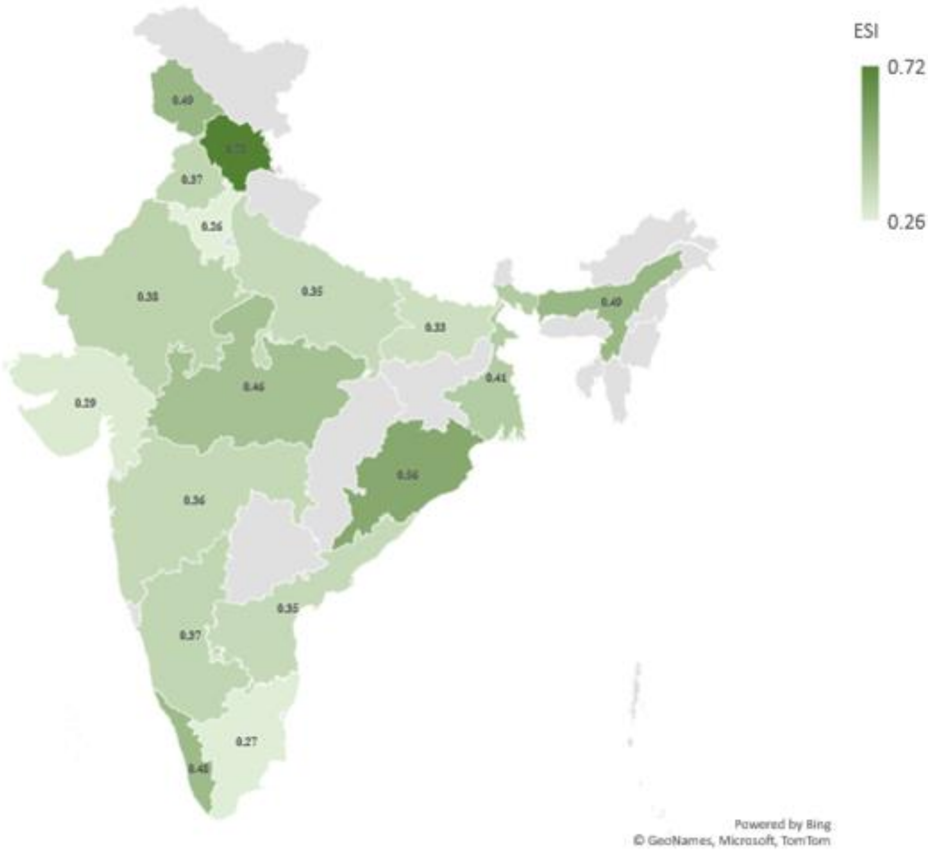

Figure 3: Comparison of Indian states based on the Ecological Security Index (ESI)

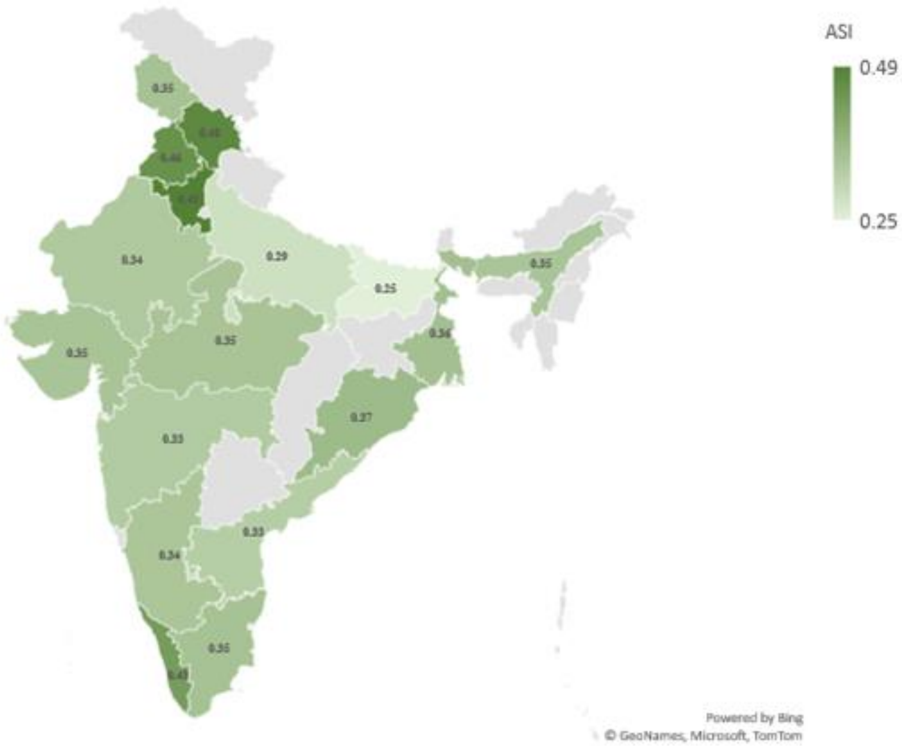

Figure 4. Performance of Indian states in agricultural sustainability

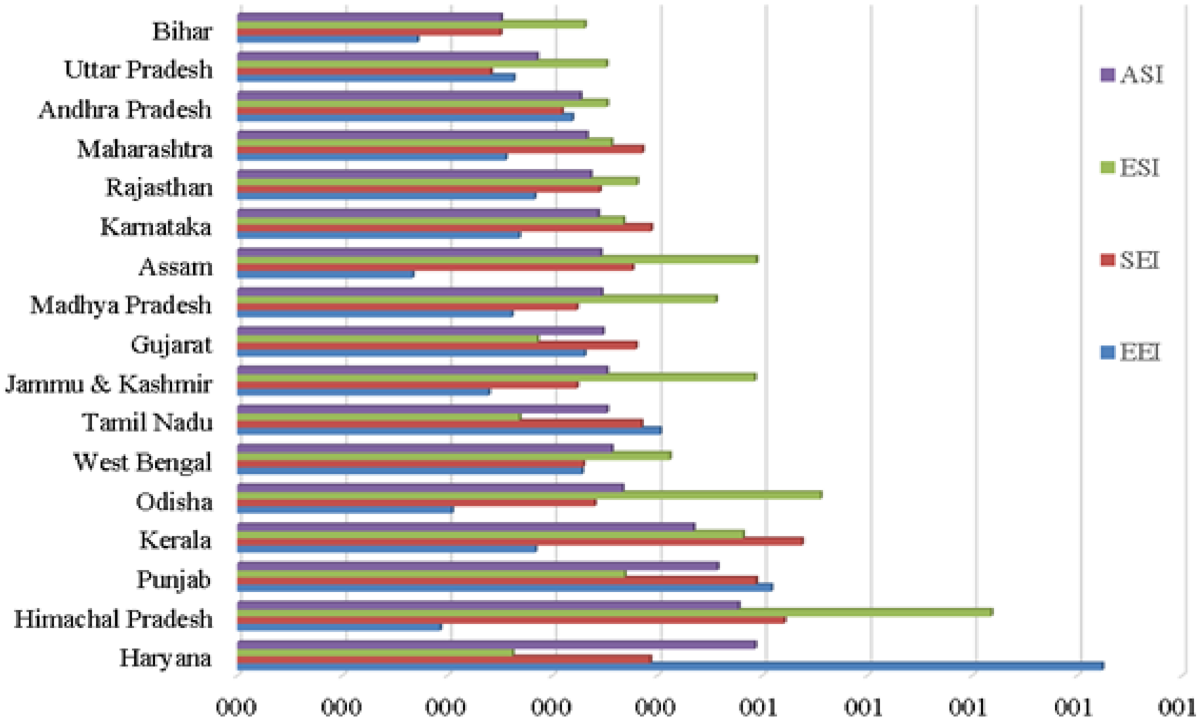

Figure 5. Comparison between states based on EEI, SEI, ESI, and ASI

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 in ASI, respectively. These two states have the better position in most factors which were the 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 states could not maintain agricultural sustainability due to several reasons such as extreme poverty, low literacy rate, high pressure of population on agriculture, low cropping 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, the Karl-Pearson correlation coefficient of ASI with EEI, SEI, and ESI was 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), and Singh et al. (2019) have also used a similar technique to identify the internal and external validity of purposed indexes. The correlation coefficient of ASI with EEI, SEI, ESI, AAMaxt, and AAMinT were statistically significant at a 1% significant level (Table 4). Thus, these indexes' 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 the 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 the variables above with ASI was estimated through linear, log-linear, and non-linear regression models. Furthermore, the panel correction standard estimation model effectively reduced 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. The mean values of the Variance Inflation Factor (VIF) for linear 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, χ^2 values under the Ramsey RESET test for powers of the fitted values of ASI and the independent variables were statistically significant at a 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% of the 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 appeared positive and statistically significant, indicating that 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. The correlation coefficient of ASI with its components and climatic factors

	ASI	EEI	SEI	ESI	AAMaxT	AAMinT	AARF
ASI	1						
EEI	0.563**	1					
SEI	0.799**	0.199**	1				
ESI	0.334**	-0.510**	0.348**	1			
AAMaxT	-0.358**	0.145**	-0.293**	-0.601**	1		
AAMinT	-0.338**	0.017	-0.182**	-0.482**	0.895**	1	
AARF	0.016	-0.212**	0.112**	0.230**	-0.042	0.122**	1

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

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

Name of models	Linear regression		Log-linear regression		Non-linear regression	
No. of Obs.	476		476		476	
VIF	3.21		5.36		489.66	
AIC	-3048.007		-1626.31		-3044.36	
BIC	-3014.684		-1592.99		-2994.38	
Ramsey RESET test using powers of the fitted values of *ASI*	0.69		2.98		0.05	
Ramsey RESET test using powers of the independent variables	1.4		43.56		1.32	
R^2	0.9786		0.9419		0.979	
Wald $\chi^2(7)$	1.01E+06		3.49E+04		1.79E+06	
Prob > χ^2	0.000		0.000		0.000	
ASI	Reg. Coef.	P>|z|	Reg. Coef.	P>|z|	Reg. Coef.	P>|z|
TTF	0.0001	0.001	0.0005	0.002	0.0001	0.009
EEI	0.3284	0.000	0.3389	0.000	0.3342	0.000
(EEI)^2	-	-	-	-	-0.0044	0.677
SEI	0.3430	0.000	0.3581	0.000	0.3597	0.000
(SEI)^2	-	-	-	-	-0.0230	0.532
ESI	0.3217	0.000	0.3548	0.000	0.3029	0.000
(ESI)^2	-	-	-	-	0.0221	0.466
AAMaxT	-0.0001	0.811	-0.1414	0.002	-0.0027	0.732
(AAMaxT)2	-	-	-	-	0.0001	0.694
AAMinT	0.0001	0.570	0.0060	0.799	-0.0029	0.321
(AAMinT)^2	-	-	-	-	0.0001	0.287
AARF	0.0000	0.007	0.0060	0.029	0.0001	0.803
(AARF)^2	-	-	-	-	-0.0001	0.836
Con. Coef.	-0.2870	0.001	-0.4337	0.201	-0.2144	0.178

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

The regression results based on a non-linear regression model showed that agricultural sustainability was non-linearly associated with economic efficiency, social equity, AAMaxT and AAMinT, and AARF. Economic efficiency, social equity, and AARF had a U-shaped function with agricultural sustainability. Thus, it also indicated a decrease in agricultural sustainability with 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 and minimum temperatures positively affect agricultural sustainability up to a certain level; thereafter, both 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 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 useful to increase India's agricultural sustainability. Therefore, there is necessary to maintain sustainability in economic, social, and environmental development to improve agricultural sustainability in India. Furthermore, the Indian 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 for economic efficiency. Per capita net domestic product, CDR, credit to the agriculture sector by a commercial bank, a 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 formulations 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 its economic capacity. 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 activities described above to improve their economic efficiency.

The values of SEI lie between 0.241-0.538 across Indian states. Thus, Indian states have high diversity in social equity due to variations 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 the most crucial determinants of social equity. Furthermore, social equity decreases with increasing birth rate and infant mortality rates. Therefore, Uttar Pradesh, Bihar, Andhra Pradesh, Madhya Pradesh, Jammu & Kashmir, West Bengal, Odisha, Rajasthan Assam, Gujarat, and Tamil Nadu are suggested to include variables described above 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 lie 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 variations 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 states performed relatively better in ecological security among the 17 states. Haryana, Tamil Nadu, and Gujarat had the 17th, 16th, and 15th positions 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 areas seemed to be the most important factor in mitigating the 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, and 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, a 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 escalating climate change and improving environmental degradation. Thus, a farming community should avoid extensive fertilizer use to maintain ecological security. Subsequently, the optimum quantity of cultivated fertilizer will help increase agricultural sustainability. The application of green fertilizer and green and appropriate technology in cultivation may help increase ecological security and agricultural sustainability in India. Furthermore, India should control population density, 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 by increasing the 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 help increase agricultural sustainability. Hence, farmers should apply agricultural and green technology to avoid climate change risks 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 positively affect agricultural sustainability. Thus, policymakers should centralize an integrated policy to increase economic development, social development, and ecological security. Climatic factors such as AAMaxT, AAMinT, and AARF significantly influence agricultural sustainability. Maximum temperature's impact on agricultural sustainability seemed negative and statistically significant. Thus, agricultural sustainability was adversely affected due to the increased maximum temperature in India. Hence, Indian farmers should apply adaptation strategies to avoid the negative impact of climate shocks on 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 farmers' adaptation strategies, mitigation approaches to climate change, and technological advancement in the agricultural sector in a further study using farm-level information.

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