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# Agricultural Sustainability and Its Trends in India: A Macro-Level Index-Based Empirical Evaluation

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**Abstract:** Sustainable development warrants cognizance of the limits of the ecosystem in terms of carrying capacity and technological externalities and, therefore, the limited extent of substitutability of natural capital with physical capital. The notion of sustainability assumes maximization and/or maintenance of current production without increasing the per unit use of inputs. In this paper, we assess the agricultural sustainability of 17 Indian states using an indicator approach for a period of two decades (1991–2011). For the analysis, the paper primarily uses the normalized temporal data for construction of indices for each of the selected indicators grouped under environmental, economic, and social dimensions. Overall, the agricultural sustainability has improved in all the states. Among the sub-components, while the social-sustainability dimension improved in all the states, the environmental and economic dimensions improved in 8 and 14 states, respectively. There was significant variation in sustainability performance among the states. Economic and environmental sustainability indices were negatively correlated. Based on the results, we advocate a strategy that negates this negative correlation. We recommend a comprehensive approach for integrating all the three dimensions for planning actions towards sustainable agricultural growth.

**Keywords:** agricultural growth; agricultural policy; environment; farm income; inequity; intensification; poverty; sustainable development goals



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## 1. Introduction

The Sustainable Development Goals (SDGs) (United Nations, 2015) are being commonly used as a "blueprint to achieve better and more sustainable future for all" by 2030, but the five years since their implementation have thrown many challenges at social planners. The SDGs visualize integrating sustainability in all forms of production, distribution, and consumption. The goals (SDG 2–end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) warrant doubling of global agricultural productivity through sustainable food production systems and resilient agricultural practices [1]. Given the declining factor productivity and population growth, this is a daunting task for several developing countries [2]. India, which has to feed a projected population of over 1.5 billion by 2030 is not an exception. The Green Revolution (GR) helped to increase foodgrain production from 108 million tonnes (mt) in 1971–1972 to 285 mt in 2018–2019. However, the chemical inputs-intensive farming practices generated many issues threatening sustainability (SDGs 3, 12, and 17), such as biodiversity loss and soil and water degradation, leading to long-term ecological costs in addition to several social and economic repercussions. In this context, sustainable agriculture alone can meet the current and long-term needs of the society for food and fibre, while maximizing the net benefits without compromising long-term ecosystem services and functions [3]. Attaining sustainability of Indian agriculture, which accounts for about 126 million hectares of farmland and provides employment to 48% of its 1.35 billion people, holds the key to achieve the sustainable development goals globally.

The sustainable agricultural system is a complex concept and evokes a multitude of responses [2] and implies an agricultural production that guarantees ecological stability, economic viability, and socio-cultural permanence [2–4]. The mainstream approach posits three basic rules for sustainable agriculture: "ecological soundness", "economic viability", and "social acceptability" [5,6]. Towards this, the agricultural development strategy has to consider a trade-off between economic benefits and social equity and environmental sustainability. The relationship between environment and economic growth is found to be of inverted-U shape [7,8]. This relationship, popularly known as the Environmental Kuznets Curve (EKC), due to its analogy to the Kuznets Curve hypothesis of Simon Kuznets [9], has led to intense debate on its existence and the reasons behind it [10]. Consequently, its analysis should consider the interdependencies among various dimensions [11]. Environmental upgrading within an economy could be due to the relocation of polluting industries to those regions with weak environmental standards [10]. The subjective bias of individuals involved in the assessment process influences the integration of diverse information on environmental, economic, and social dimensions of sustainability and the handling of conflicting aspects on these objectives [12]. The past attempts to assess the sustainability of agriculture in India [13,14] considered a limited set of variables, spanning over a short period. The objective of the present paper is to assess the trend in the agricultural sustainability in India at the sub-national level. Towards this, the paper constructs agricultural sustainability indices for 17 major states (sub-national administrative units) of India, using 24 variables for the years 1991, 2001, and 2011. The paper provides empirical evidence for our hypothesis that, over the years, Indian agriculture has turned to be more sustainable, albeit with large regional variations. The paper also helps in focusing the regional and sectoral strategies for achieving the SDGs.

The paper contributes to the literature on agricultural sustainability in three difference ways. First, it provides a methodological framework for integrating environmental, economic, and social dimensions using the DPSIR framework. Second, the study utilises variables that have policy relevance in terms of framing rules, regulations, and investment decisions. National agricultural policy, national forest policy, water policy, fertilizer pricing policy, land use policy, and livestock policy are relevant in the context. Further, policies with respect to marketing, credit, and incentives for crop diversification turn out to be relevant. The variables included are based on secondary data that are considered in policy deliberations. They are rather easily available at national and sub-national levels also, and, therefore, can be replicated for similar locations. Third, the methodology allows comparison over years and is dynamic in nature. It constructs an agricultural sustainability index for a period of 20 years, which helps to reflect upon the policies that have contributed to such a change.

## 2. Materials and Methods

The methodological frameworks to analyse sustainability at various scales, like farm or community or district levels or even at higher levels including various countries, lack consensus [15] due to the conceptual issues involved in defining agricultural sustainability and determining its boundaries. Many organisations—including the European Environment Agency (EEA), OECD, the United Nations, and World Bank—have developed frameworks for the estimation of agricultural sustainability with some differences in their approaches, properties of sustainable agricultural system that are proposed as criteria for sustainability assessment, and selection of dimensions for assessment [16]. There is wide heterogeneity in data, scales, issues, and final goals of sustainability assessments [17], as agricultural sustainability is contextual, location-specific, and dynamic and involves complex interactions between technologies, environment, and society [18]. The three components of sustainability, viz., environmental, economic, and social, are highly interactive and overlapping too.

### 2.1. Pressure-State-Response Model

The Organisation of Economic Cooperation and Development (OECD) introduced the Pressure-State-Response (PSR) framework for addressing the problem of systematic identification of the indicators, and it is the most widely accepted framework for measuring sustainability [16]. This concept relies on the principle of causality, i.e., human activities pressurise environment and change its state and evoke human responses. Accordingly, the PSR framework has three important dimensions, viz., pressure, state, and response. Pressure refers to the human activities which influence the environment leading to a change in its quality (state), towards which the society responds through various policies. Some other models are the Driving Force-State-Response (DSR) model and Driving Force-Pressure-State-Impact-Response (DPSIR) framework [16] (Woodhouse et al., 2000), which can be considered as variants of the PSR model. A schematic representation of the DPSIR framework is provided in Figure 1.

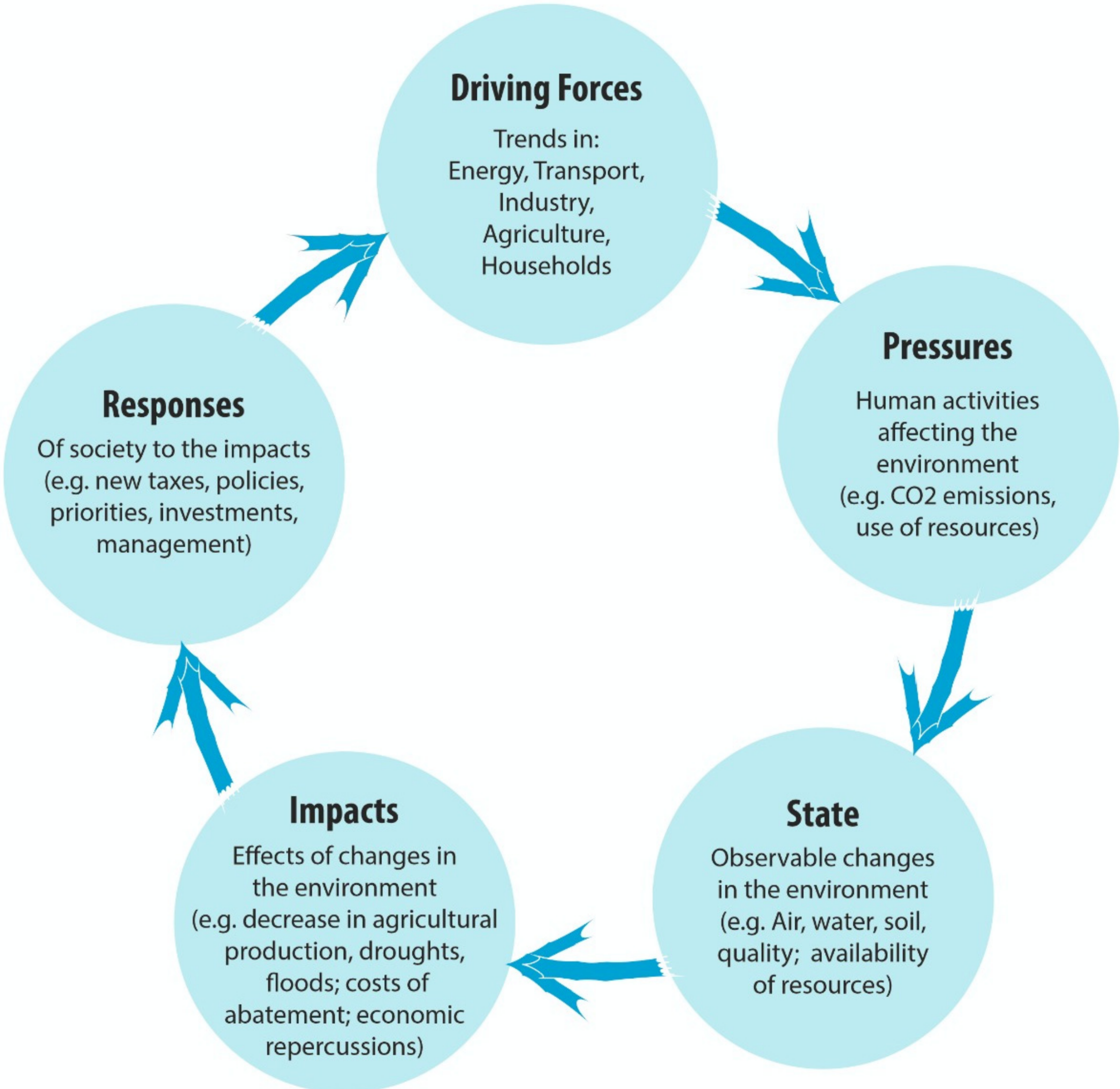


**Figure 1.** DPSIR framework of sustainability (Adapted from Woodhouse et al., 2000 [16]).

With a growing sustainability knowledge base, Sustainable Development Indices (SDI) are commonly employed in sustainable agriculture models [19]. Sustainability indicators are quantifiable and measurable attributes of a system related to sustainability [20]. There are several shortcomings of the index approach for estimating the sustainability [21], a synthesis of which is provided by [22]. Notwithstanding these shortcomings, the indicator approach serves some useful functions.

For this study, as a first step, following the DPSIR framework, indicators were identified, keeping in view the environmental, economic, and social dimensions. The indicators were selected based on the four components, viz., agro-ecosystem, agro-ecosystem stress, agro-ecosystem vulnerability, and agro-ecosystem management, following [18]. Variables under these components, falling under the environmental, economic, and social dimensions of sustainability, were identified. Availability of comparable secondary data was an important consideration while selecting the variables. A schematic diagram of the methodology is provided in Figure 2. The details of the variables identified to construct sustainability indices are provided in Table 1.

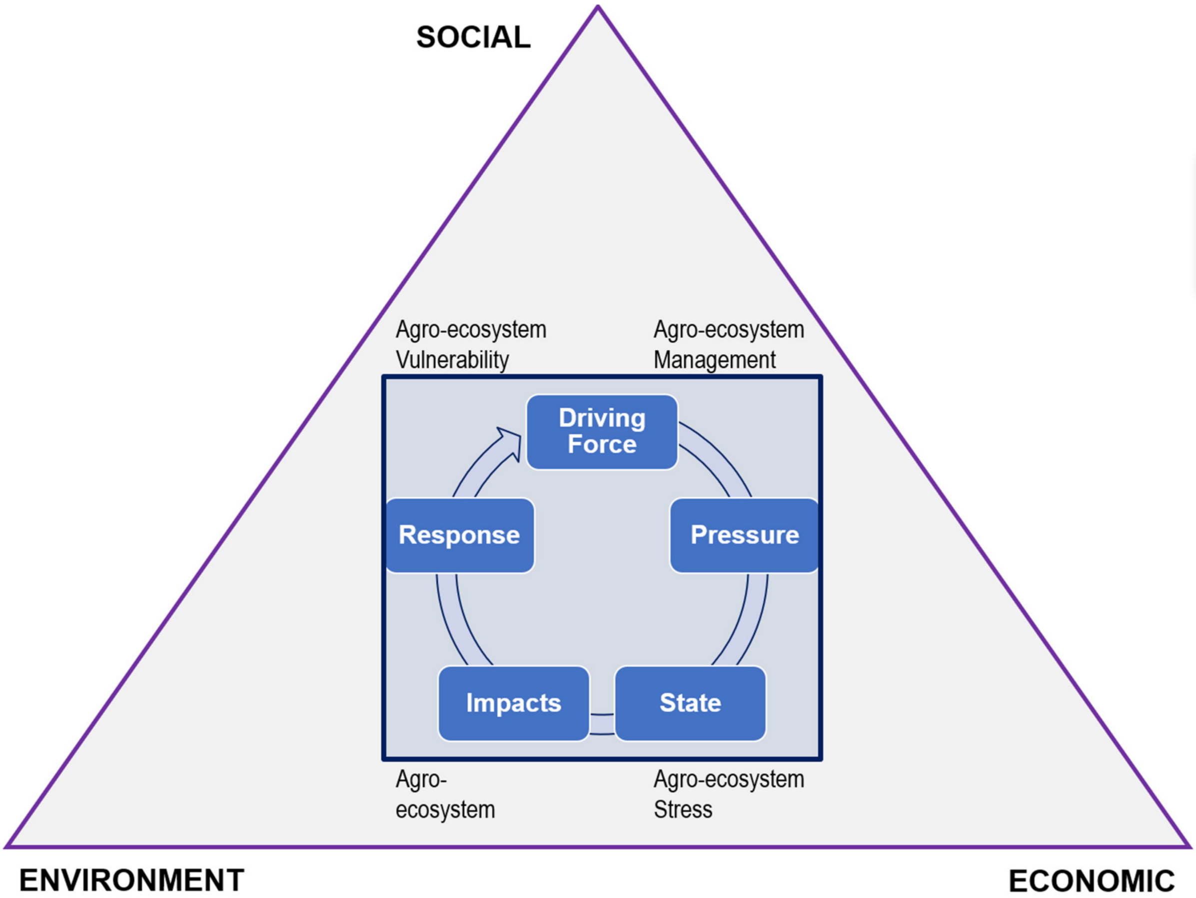


**Figure 2.** The framework used for constructing the sustainability index.

**Table 1.** Details of the variables identified to construct sustainability indices.

| Variable/Indicator | Hypothesis | Expected Sign | Component | Remarks/Reasoning |
|---|---|---|---|---|
| | | **Environmental Dimension** | | |
| Area under forests (%) | Area under forests contributes to agricultural stability. | +ve | Agro-ecosystem | Apart from being a resource to the farmers in terms of providing food, fodder, timber, and minor forest products, forests provide many ecosystem services and contribute towards biodiversity conservation. The share of forests in total geographical area was used. |
| Agricultural land use intensity (%) | Land intensification has negative influence on ecosystem stability. | −ve | Agro-ecosystem | Land use activities, mainly agriculture, have profound negative influence on ecosystem services and environment, due to disturbance of soil, loss of biodiversity, and jeopardising ecosystem services. The net sown area as a share of total geographical area was used. |
| Agricultural chemical use intensity (kg/ha) | Intensive use of agrochemicals has negative impacts. | −ve | Agro-ecosystem stress | Intensive use of agricultural chemicals results in land degradation due to contamination of soil and water bodies, eutrophication, heavy metal toxicity, and chemical residues, thereby adversely affecting agricultural stability. Application of nitrogen, phosphorous, and potassium per hectare of cultivated area was used. |
| Ground water depletion (%) | Depletion of groundwater level affects the hydrological cycle, and thereby the sustainability. | −ve | Agro-ecosystem stress | Increasing dependence of agricultural production on groundwater has resulted in its over-exploitation. This results in depletion of aquifers at a faster rate than the rate at which they can be recharged. Due to this, the ability of the system to cope with drought and other adverse climate conditions is hampered. Stage of groundwater development, expressed as percentage, was used as the indicator variable. |
| Livestock intensity per net cropped area (Number/ha) | Number of livestock per hectare of net cropped area imparts sustainability to farming. | +ve | Agro-ecosystem vulnerability | Integrated crop-livestock systems lead to better nutrient cycling, biomass utilisation, and accumulation of soil carbon. Number of livestock expressed as Adult Cattle Unit per hectare of cultivated area was used. |
| Rainfall variability (%) | Rainfall variability has significant negative impact on agricultural sustainability. | −ve | Agro-ecosystem vulnerability | While rainfed agriculture accounts for large share of the total crop area (53%), variability in the rainfall pattern causes disruption in crop production, leading to crop loss, farm income loss, affecting agricultural sustainability. Coefficient of variation of rainfall in the preceding decade was the indicator variable. |
| Fertilizer imbalance (index) | Fertilizer imbalance negatively impacts agricultural sustainability. | −ve | Agro-ecosystem management | Fertilizer imbalances are likely to create a nutritional imbalance, which directly affects the crop resistance to insect pests and diseases. This ultimately limits the agricultural sustainability. Fertiliser imbalance index was constructed following [23]. |
| Cropping intensity (%) | High cropping intensity significantly contributes to agricultural sustainability. | +ve | Agro-ecosystem management | High cropping intensity promotes diversified and integrated farming, nutrient recycling, better resource usage, and climate regulation and imparts resilience to the agricultural production systems. It negates the need to clear forests to expand cultivated area. The cropping intensity was calculated as the ratio of gross cropped area to net cropped area, expressed as percentage. |

**Table 1.** *Cont.*

| Variable/Indicator | Hypothesis | Expected Sign | Component | Remarks/Reasoning |
|---|---|---|---|---|
| | | | **Economic Dimension** | |
| Land productivity (Rs/ha) | Higher land productivity contributes to sustainability. | +ve | Agro-ecosystem stress | An indicator of efficiency of agricultural production that results in bridging the yield gap. It was captured by the value of output per hectare in real prices. |
| Per capita food grain production (PCFGP) (kg/year) | Direct relationship with agricultural sustainability. | +ve | Agro-ecosystem | PCFGP is an indicator of general food availability and food self-sufficiency in most of the developing countries. It was captured as the foodgrain production per population. |
| Factor productivity (Rs/kg) | Consistent growth in factor productivity indicates sustainability of agricultural systems. | +ve | Agro-ecosystem vulnerability | A sustained and non-negative trend in factor productivity growth implies that the system is sustainable. The indicator variable was calculated as the productivity in value terms per kg of total NPL nutrients. |
| Per capita income (PCI) (Rs) | Per capita income has positive influence on sustainability of agricultural sector. | +ve | Agro-ecosystem | Higher PCI leads to structural transformation, where composition of inputs and methods of production shifts in favour of less destructive production systems. Further, higher PCI contributes to higher demand for environmental quality and sustainably produced foods. PCI was calculated in real terms. |
| Energy productivity (Rs/kwh) | Higher energy productivity positively influences agricultural sustainability. | +ve | Agro-ecosystem vulnerability | Considering reliance of agri-food systems on the energy sources, viz., diesel and electricity, the higher the efficiency and productivity of those resources, the greater is the abatement of environmental externalities and the cost effectiveness. The indicator variable was value productivity in terms of unit of electricity used. |
| Man-land ratio (Number) | Man-land ratio has negative influence on agricultural sustainability. | −ve | Agro-ecosystem stress | Higher population per unit arable land accelerates the exploitation of resources and demands intensive agricultural production, posing a greater threat to agricultural sustainability. The variable was constructed as the ratio of the population to net cropped area. |
| Irrigated area (%) | Irrigation imparts resilience and influences agricultural sustainability positively. | +ve | Agro-ecosystem management | Irrigated area stands as key determinant in the sustainable agricultural strategies by reducing the risks in farm production and helping in higher production. In addition, it greatly helps in realization of land use potential. Irrigation scheduling and proper water balance regulates several plant growth mechanisms. The variable was constructed as the ratio of net irrigated area to net cropped area, expressed as percentage. |
| Road transport (km) | Road transport has significant impact on agricultural production and has positive association with agricultural sustainability. | +ve | Agro-ecosystem management | Road density influences agricultural productivity by facilitating easy access to input and output markets, reducing spoilage, reducing fuel loss and transportation cost. In addition, better road transportation facilities generate more farm income. The variable was constructed as road length in km per 1000 square km of geographical area. |

**Table 1.** *Cont.*

| Variable/Indicator | Hypothesis | Expected Sign | Component | Remarks/Reasoning |
|---|---|---|---|---|
| | | | **Social Dimension** | |
| Literacy rate (%) | Literacy rate has positive association with sustainability. | +ve | Agro-ecosystem | Improvement in literacy enhances agricultural production by reducing information asymmetry, facilitating social capital, imparting awareness on technical opportunities, and improving technical efficiency. The indicator variable was adult literacy rate expressed as percentage. |
| Rural poverty (%) | Increase in rural poverty has significant negative influence on growth and sustainability of agriculture. | −ve | Agro-ecosystem vulnerability | Population growth is a determinant of land degradation, deforestation, and pollution worldwide. In addition, rural poverty threatens the food and nutritional security. The indicator variable was rural poverty as headcount ratio, expressed as percentage. |
| Income inequality (Gini coefficient) | Income inequality has negative influence sustainability. | −ve | Agro-ecosystem stress | Inequality in the distribution of land and non-farm employment is the major determinant of income inequality. Growth of agricultural sector is considered as a major factor in reducing the income inequality, thus negatively influencing agricultural sustainability. The indicator variable was Gini coefficient of income distribution. |
| Infant mortality rate (IMR) (Number) | Rise in the IMR is negatively linked to the agricultural growth and sustainability. | −ve | Agro-ecosystem vulnerability | IMR and child health among rural and farm communities is directly linked to the food and nutritional security, which is both a cause and effect of agricultural growth and its sustainability. The variable was number of death per 1000 births of children under one year of age. |
| Access to institutional credit (%) | Access to institutional credit has positive association. | +ve | Agro-ecosystem management | Rise in the share of institutional credit to the agricultural households is a clear indicator of an enabling ecosystem of policy interventions to protect the farmers from financial exclusion. Timely credit support helps farmers to meet the overall credit requirements throughout the crop. The indicator variable was share of institutional credit in outstanding cash debts of the state in rural areas. |
| Sex ratio (Number) | Rise in the sex ratio has positive association. | +ve | Agro-ecosystem | Investing in gender equality and providing equal access and opportunities to have equal control of resources, lands, and markets can unlock human potential on a transformational scale. In addition, the improved earning outcomes as a result of women participation has positive impact on the livelihood of farming households. The variable indicated number of females to 1000 males. |
| Non-farm income (%) | Non-farm income has significant positive influence on sustainability. | +ve | Agro-ecosystem | Strategies to wean out farmers from the farm sector by providing gainful employment opportunities in non-farm sectors have provided rich dividends in the economic growth of many countries through transfer of disguised unemployed labourers from agricultural sector to industrial sector, without affecting agricultural productivity. The share of non-farm sector in rural employment was used as the indicator variable. |
| Rural workforce participation rate (%) | Rural workforce participation rate has positive association with agricultural sustainability. | +ve | Agro-ecosystem management | Agricultural labourers constitute a major segment of the rural workforce. Increase in their participation rate indicates availability of sufficient on-farm employment opportunities, resulting in higher agricultural output and its sustainability. Work participation rate was the ratio of total workers to the total population multiplied by 100. |

*2.2. Normalisation of Indicators*

Aggregation of a diverse set of indicators into a unique composite indicator is needed to understand the complex concept of agricultural sustainability [24]. The indicators used for the assessment can be calculated using various techniques, among which more popular methods are sums or weighted means or normalization technique [6].

The sustainability indices were constructed following the approach for constructing the Human Development Index (HDI) being calculated by the United Nations Development Programme (UNDP). Let $X_{ijk}$ and $ASI_{ijk}$ denote, respectively, the value of *i*th variable representing the *j*th component of the index of the *k*th region. When the observed values were related positively to the sustainability, normalisation was achieved by using the formula:

$$= \frac{X_{ijk} - minX_{ijk}}{maxX_{ijk} - minX_{ijk}}$$

On the other hand, when the values of $X_{ijk}$ were negatively related to the sustainability, the normalised values were computed by the formula:

$$= \frac{maxX_{ijk} - X_{ijk}}{maxX_{ijk} - minX_{ijk}}$$

The normalised values of this index lied between 0 and 1.

The sustainability indicators for each dimension were aggregated by using equal weights as in the present study. The data exhibited large variation among different variables. Accordingly, each variable in each dimension had a weight of 1/8. Finally, all three dimensions were aggregated with a weightage of 1/3. Thus, a variable had a weightage of 1/24 in the final agricultural sustainability index, ensuring that no single variable would unduly influence the final index.

*2.3. Temporal Changes in the Sustainability Indicators*

Imparting dynamic nature to the indicators is important for quantitative assessment of the sustainability wherein there is consideration of various functions of the agro-ecosystem and their variations in time, which facilitate with the opportunities for modification or change [25]. Construction of the sustainability index at the state level is carried out for three points of time, viz., 1991, 2001, and 2011. Construction of an index for a particular year by taking the maximum and minimum values for that year alone would provide an index relevant only for that particular year, rendering inter-year comparison infructuous. To overcome this problem and to make the index dynamic, the maximum and minimum values for each variable were selected out of the data for three years. This enabled comparability and aided in ascertaining the trends and ranks of the states. A total of 17 major states were included in the analysis, as existed in 1991. These 17 states would cover about 98% of the net cropped area and total population of India. Data for the states, which were bifurcated during recent periods, were calculated for the original states by using weighted averages.

## 3. Results and Discussion

*3.1. Variables under Environmental Dimension*

3.1.1. Area under Forest

Forests provide several ecosystem services which are useful for agriculture, viz., regulating climate and water cycle, regulating carbon dioxide and oxygen, and helping carbon sequestration. The provisioning services of forests include supply of products (timber and non-timber) which form food and livelihood sources, notably for marginalised sections of society and tribal communities, thereby minimising pressure on cultivated land. The modern crop breeding programmes are founded on genetic diversity of forests which provide sources of such genetic materials.

The area under forests as a share of total geographical area has made a slight improvement at the national level, from 22.3% in 1991 to 22.8% in 2011. The status and performance of the states varied considerably against this indicator, with the share of forests ranging from as low as 0.9% in Haryana to as high as 54% in Jammu and Kashmir.

#### 3.1.2. Agricultural Land Use Intensity

The pressure to produce food triggers the transfer of land, mostly from the ecologically sensitive category, to cultivation. Land conversion from natural ecosystems has destructive impacts on ecosystem services, as in the case of conversion of tropical forests and temperate grasslands to agriculture [26,27].

To desist from cultivation in ecologically sensitive lands, the USA provides yearly rental payment to farmers. Under the "grain for green program", China pays farmers for reverting to cultivation of grasses and trees in the sloppy terrains, instead of cultivating grain crops [28]. The increased monoculture and mono-cropping have resulted in the loss of productivity. In this background, the land intensification, measured as net sown area as a percentage of total geographical area, was hypothesised to have a negative influence on stability. At the national level, about 46.3% of land is cultivated, and the share has remained constant over the years, though with wide variations across the states.

#### 3.1.3. Agro-Chemical Use Intensity

Usage of the major plant nutrients, viz., nitrogen (N), phosphorous (P), and potash (K), in the form of chemical fertilizers per hectare was used to depict this indicator, and a negative sign was hypothesised. The usage of fertilizer nutrients in India increased from 70 kg/ha in 1991 to over 140 kg in 2011, ranging from 59 kg in Odisha to over 250 kg in Punjab (Table S1).

Increased cereal production in the world over the past 50 years has seen increased application of inputs like water, pesticides, and nutrients [29]. The increased production by the intensified agriculture was also accompanied by land and water degradation and non-point source of pollution, constraining the growth in agricultural production and stability [30,31]. The major negative impacts on environment due to fertilizer addition include eutrophication of surface waters (particularly freshwater streams and coastal seas), biodiversity loss, degradation of water quality downstream, depletion of the ozone layer, and acidification of soils [32]. Toxicity to non-target organisms and humans is a major risk of elevated levels of pesticides use [33].

#### 3.1.4. Groundwater Depletion

The variable considered in the study was the stage of groundwater development, supplied by the Central Groundwater Development Board (CGDB), Government of India. The groundwater-based irrigation system accounted for 63% of the net irrigated area in India during 2011–2012 (Table S2). Over the years, the net area irrigated as a share of the total cultivated area, and the usage of groundwater in it, has increased. In some states like Punjab, Rajasthan, and Haryana, the stages of groundwater development were as high as 177%, 137%, and 133%, respectively. This has several equity implications, affecting the interest of the small and marginal farmers [34]. Expansion of the area under irrigation, particularly groundwater-based irrigation, has led to the degradation of water resources and soil deterioration [35]. In view of the decline of groundwater to alarming levels in many parts of India, a negative relation was hypothesised.

#### 3.1.5. Livestock Intensity per Net Cropped Area

In India, livestock is extensively used for draft power, and obtaining organic matter and nutrients, and has remained an integral part of farming. The number of livestock per hectare of net cropped area is used as a positive factor that imparts sustainability to farming. At the national level, it marginally increased from 2.5 in 1991 to 2.6 in 2011. Some states, viz., Karnataka, Kerala, and Tamil Nadu, showed a consistent decline, whereas

Andhra Pradesh, Madhya Pradesh, and Gujarat have shown a consistent increase. In many parts of India, livestock is a buffer against shocks arising out of climate vagaries like drought. Integrated crop-livestock systems lead to better nutrient cycling, biomass utilisation, and accumulation of soil carbon and, therefore, renders farming ergonomically and environmentally efficient and sustainable [36,37].

#### 3.1.6. Rainfall Variability

Rainfall variability was estimated by the coefficient of variation (CV) of rainfall during the preceding decade, and a negative value was hypothesised. Climate change manifests as short-term variability of weather variables, and it has accentuated the threat of food insecurity among many farming communities [38]. The negative consequence of rainfall variability on agriculture includes reduced productivity, increased crop disease incidents, and drastic reduction in soil fertility [39]. The monsoon variation, particularly those resulting in severe drought, causes 2 to 5% reduction of Indian GDP [40]. Weather variability acts both as a push and pull factor for inter- and intra-state migration of farmers [41].

#### 3.1.7. Fertilizer Imbalance

Broadly, N:P:K ratio of 4:2:1 is considered ideal at the national level. The fertilizer imbalance was calculated following the methodology used by other researchers [23]. The trend in the indices of fertilizer imbalance is provided along with the usage of NPK, in Table S1, wherein a higher value represented a higher level of imbalance. The CV of fertilizer imbalance among the states was found to increase over years, largely reflecting their administrative efforts to reduce it.

The consumption of chemical fertilizers in agricultural production is imbalanced [30]. Fertilizer usage in India is imbalanced, in favour of higher nitrogen level. The imbalance affects plant nutrient intake, soil fertility, crop productivity, and profitability. Over the years, the marginal productivity of fertilizers has declined.

#### 3.1.8. Cropping Intensity

The cropping intensity at the national level has shown consistent increase, and was as high as 180% in West Bengal. High cropping intensity promotes integrated farming and better resource usage and imparts resilience. It also helps in nutrient recycling and climate regulation and is considered to positively affect the environment [42]. Further, it avoids the necessity for clearing the forest lands.

### *3.2. Variables under Economic Dimension*

#### 3.2.1. Land Productivity

Land productivity, expressed as value of output per hectare, indicates the efficiency of agricultural production. It is calculated by dividing the value of crop outputs (at 2004–2005 constant prices) obtained from the Central Statistical Office (CSO) with the net area sown for each state. Higher values indicated better efficiency, and, therefore, growths in it indicated sustainability.

The value of output on a per hectare basis and its compound annual growth rates are provided in Table S3. In 2011, the mean value of output for the crop sector at all India levels was about Rs 41,000/ha (at 2004–2005 price). Among the states, the highest value was in Himachal Pradesh (Rs. 150,000/ha), followed by West Bengal and Punjab (Rs. 87,000/ha). However, a disconnect between the trends in the value of output and foodgrain production was noticed in Himachal Pradesh, Jammu and Kashmir, Kerala, and West Bengal [43] because of the differences in the shares of high value commercial crops among the states.

At the national level, the annual average growth rate was 2.14% during 1991–2001 (first period), and it increased to 2.96% during 2001–2011 (second period). Out of the 17 states, growth rates reduced in nine states during the second period. In the first period, growth rates above 4% were observed in Bihar (6.43%), Karnataka (4.74%), and Tamil Nadu (4.19%), whereas negative growth rates were observed in two states, viz., Jammu and Kashmir (−3.65%) and Gujarat (−0.84%). In the second period, six states recorded more than 4% growth rate, the highest being in Gujarat (8.36%), followed by Madhya Pradesh (6.54%) and Himachal Pradesh (6.45%). The sharp reversal of output growth in Gujarat could be due to groundwater recharge [44], spread of Bt cotton [45], and consistent 'above-normal' monsoons for quite a long period [25]. A reduction in growth rates was observed in Haryana, Punjab, and Uttar Pradesh. Reduced growth rates were also noted in all the southern states, except Andhra Pradesh (undivided). This could be pointing to higher growth in hitherto states with slow growth, and a reduction in growth in high performing states, leading to a convergence in agricultural growth. The CV of growth rates reduced from 118% to 70%. In India, reduced instability with progress of technology adoption is noted for major foodgrains [46] and the commercial crops like cotton.

#### 3.2.2. Per-Capita Foodgrain Production (PCFGP)

Maintaining growth in foodgrain production above the population growth is important to meet the increased demand. A negative trend in PCFGP points to inadequate domestic production, high food-price inflation, and possible negative impacts on food and nutritional security. Growth in foodgrain production above the population growth is crucial to maintain food availability, one of the components of food security. At the national level, *PCFGP* in 2015 was 170 kg, whereas the peak production of 186 kg was attained in 1991 (Table S3). The annual per capita foodgrain production ranged widely from 16 kg/person in Kerala to 1004 kg/person in Punjab. During the first period, 10 out of 17 states recorded negative growth in PCFGP, but in the second period, only six states recorded negative growth. Sharp reversals were observed in Gujarat, Himachal Pradesh, Madhya Pradesh, Maharashtra, Odisha, and Rajasthan. Further, early Green Revolution states in India in the Indo-Gangetic plain, viz., Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal, which contribute much to the wheat and rice production in India, showed deceleration.

#### 3.2.3. Fertilizer Productivity

A positive total factor productivity (TFP) growth has been considered as an indicator of sustainability. Since fertilizer is the major non-labour input in the variable cost component in agriculture, partial fertilizer productivity (PFP), calculated at 2004–2005 constant prices was used. From 1991 to 2011, at the national level, the value of output per fertilizer nutrient reduced by 22% to reach Rs 278/kg. The highest value of output per fertilizer usage was noticed in states with significant share of plantation and cash crops. Importantly, all the states recorded a negative change in the fertilizer productivity during 2001–2011, pointing towards deteriorating sustainability.

#### 3.2.4. Per Capita Income (PCI)

PCI is an indicator of standard of living and has a significant influence on access to inputs and resources. It also influences access to health care and educational facilities. The PCI consists of income from agriculture, industrial, and service sectors and is hypothesised to have positive association. The PCI ranged from Rs 15,035 in Bihar to Rs 59,587 in Maharashtra in constant price (Table S4). The second period showed higher growth over the first period in 12 states.

#### 3.2.5. Energy Productivity

Diesel and electricity are the major commercial energy sources for agriculture. Improving energy efficiency is significant to render agriculture cost effective. During the period 1985–2013, the electricity usage in Indian agriculture increased from 20,960 to 168,913 Gwh. Agriculture accounts for about 21% of total electricity consumption. The energy productivity in agriculture is calculated as value of output per unit of electricity used. High variation is due to the variations in several factors, viz., the usage of electricity, infrastructure development, presence of high value crops, and development of processing industries.

#### 3.2.6. Man-Land Ratio

The carrying capacity of the systems as determined by the human population on unit of net cropped area is a pressure variable. At the national level, the ratio stood at 8.55 per hectare of net sown area in 2011, up from 5.92 in 1991, and it increased in all the states. The ratio was as high as 21.6 in Bihar and 18.3 in West Bengal. Population pressure triggers agricultural intensification [47]. A high man-land ratio coupled with low productivity leads to disguised unemployment.

#### 3.2.7. Irrigated Area

Irrigation helps to augment productivity and farm income with a reduction in risk. Irrigation development is limited by availability of water, capital constraints, and technological feasibility, and, therefore, increased irrigation efficiency is desired. The irrigation coverage was observed to have improved in most states (Table S3). As in 2011, the irrigation intensity was 98% (of the net cropped area) in Punjab, 86% in Haryana, and 82% in Uttar Pradesh, but was quite low in the peninsular Indian states, except in Andhra Pradesh (46%) and Tamil Nadu (60%).

#### 3.2.8. Road Density

Variation in the road density (km/1000 km$^2$) was taken as an indicator, as it influences agricultural productivity by facilitating easy access to input and output markets, reducing spoilage, and reducing fuel loss and transportation cost. The mean road density was 1015 km, with wide variations among the states ranging from as low as 100 km in Jammu and Kashmir to more than 5269 km in Kerala.

### *3.3. Variables under Social Dimension*

#### 3.3.1. Literacy Rate

The literacy rate in India was found to have improved significantly over the years, by over one percentage point every year to reach 74% in 2011. It varied from 64% in Bihar (combined) to 94% in Kerala. Literacy enhances agricultural production by reducing information asymmetry, facilitating social capital, and improving technical efficiency [48]. In the transformation of a rural economy to a non-farm oriented one, investment in education would have high payoffs, as the educated one stands to gain more [49]. In this context, a positive relation was hypothesised.

#### 3.3.2. Rural Poverty

The rural poverty estimates available for the years 1993–1994, 2004–2005, and 2011–2012 were used. The rural poverty in India, as a head-count ratio, reduced from 50.1% to 25.7% over the period (Table S4), with large inter-state variations. There were targeted programmes to reduce the poverty in India, with differing impacts. In the long term, agricultural sustainability plays a critical role in addressing rural poverty. Continued population growth in association with increased inequity of land and other resources forces the poor to expand agriculture into ecologically fragile areas, furthering deforestation and compromising the productive potential. Poverty is the biggest enemy of the environment, including land degradation, and it sets in a spiral and vicious circle with respect to its relationship with the environment and economic progress [50]. Investment in the agricultural sector is more effective in terms of reducing rural poverty, compared to several other investments avenues [51,52]. In India, the head-count poverty estimates represent the proportion of the population having food expenditure that would hinder access to certain prescribed minimum levels of calorie intake.

#### 3.3.3. Income Inequality

In addition to misallocation of resources, income inequality has several social repercussions. It is also closely related to the governance structure and existence of institutional backups [53]. In India, most of the states have large heterogeneous populations with respect to access to land, means of livelihood, and social amenities. The economic differences along with social differences have widened within and across states and districts in India [54]. The rural income inequality, measured by the Gini coefficient, decreased from 0.28 in 1993–1994 to 0.26 in 1999–2000 but increased to 0.28 in 2009–2010 (Table S4). The Gini coefficient increased in six out of 17 states. High inequality in rural incomes could be attributed to skewed ownership of land along with physical and financial assets [55]. The growth of the agricultural sector has a significant role in reducing inequality [56].

#### 3.3.4. Infant Mortality Rate (IMR)

The IMR of children under 5 years old has shown a significant reduction from 80 in 1991 to 44 in 2011. Health is a cause and effect of agricultural development [57]. IMR is a critical social outcome of the complex interaction of agricultural growth, food and nutritional security, availability of safe drinking water, and health care facilities. It is a comprehensive variable that reflects the health of both child and mother.

#### 3.3.5. Access to Institutional Credit

Farmers depend on a multitude of sources of credit to meet short-term crop loans and for long-term farm investment loans. Though there were several attempts by the government to channelize institutional credit for the agricultural sector [55,58], many farmers still continue to avail credit from non-institutional sources including money lenders, often at a usurious rate of interest. The share of institutional credit in total credit for the farm sector accounted for about 60.3% in 2013, up from about 55.7% in 1992 [54].

#### 3.3.6. Sex Ratio

There is evidence to suggest that the traditional agricultural societies tend to prefer men over women, due to the physical power required for agricultural operations [59]. Several social and economic dimensions too are influencing the sex ratio. This includes migration and labour participation in agriculture [60]. Gender empowerment is a main function of agricultural growth. Sex ratio, expressed as number of females per 1000 males, can serve as an indicator of gender justice and social sustainability.

#### 3.3.7. Non-Farm Income

Non-farm income is crucial for poverty alleviation. In India, the share of the non-farm sector in rural employment has shown a slow increase, from 21.7% in 1991 to about 32.1% in 2011. As in 2011, Kerala (64.3%), West Bengal (43.7%), and Jammu and Kashmir (40.3%) have the highest share of the non-farm sector in total employment (Table S5). The slow development and labour productivity in the agricultural sector in India are attributed to the relatively low development of non-farm sector in lifting out the rural poor. The situation of high population pressure and land degradation coupled with slow technological progress warrants development of the rural non-farm sector in developing countries [61]. Non-farm income is found to have contributed towards absorbing the excess labour present in the agricultural sector, increasing household income, and reducing poverty, in addition to contributing to the improvement in the agricultural income as well in China [62]. However, enclave agriculture that focuses on export of agricultural commodities contributes to shrinkage of the manufacturing sector, and that along with strong linkage with the domestic economy limits the magnitude of the shrinkage [63]. Non-farm income exerts significant impact on a household's total income in developing countries. The non-farm sector also acts as a source of finance when the credit markets do not function in rural areas [64]. Strategies to wean out farmers from the farm sector by providing gainful employment opportunities in non-farm sectors have provided rich dividends in the economic growth of many countries. Lewis, in his famous structural change theory, visualises transfer of disguised unemployed labourers from the agricultural sector to industrial sector, without affecting productivity [31,65].

#### 3.3.8. Rural Work Participation Rate

The work participation rate depicted wide variations from 34% in Uttar Pradesh to 52% in Andhra Pradesh (Table S5). Over the years, the non-farm sector work participation rate has progressed in the majority of the states. Higher work participation by the working age group points to the ability of the system to incentivise the labour force to contribute to income-generating activities and is related positively with sustainability. Generating more local employment and participation are important functions of sustainable agriculture [2].

### 3.4. Agricultural Sustainability at State Level

#### 3.4.1. Environmental Sustainability

The descriptive statistics of different indices is provided in Table 2. The mean environmental sustainability index was 0.510 in 1991, which improved slightly in 2001 but showed a reduction subsequently. Among the states, Jammu and Kashmir and Himachal Pradesh showed the highest environmental sustainability in all three years (Table S6), which could be attributed to a relatively higher share of area under forest, low groundwater development, high livestock density, and low fertilizer usage. The lowest performance, as in 2011, was registered by Punjab followed by Haryana, which are characterised by low area under forests, higher land use and fertilizer intensities, high fertilizer imbalances, and highest groundwater usage. These states were the early adopters of Green Revolution technologies and continue to be the foodgrain basket in India. During 1991–2001, several states have improved their relative positions, notable among them being Andhra Pradesh, Maharashtra, and Tamil Nadu. On the other hand, Assam, Gujarat, Karnataka, Punjab, Rajasthan, and Uttar Pradesh have shown deterioration. Overall, the results indicated consistency at both the extremes, with some variations in the states appearing in between.

**Table 2.** Descriptive statistics of sustainability indices.

| Parameters | 1991 | 2001 | 2011 |
|---|---|---|---|
| Environmental sustainability index | | | |
| Mean | 0.510 | 0.514 | 0.508 |
| Minimum | 0.293 | 0.315 | 0.292 |
| Maximum | 0.795 | 0.786 | 0.801 |
| Standard Deviation | 0.138 | 0.133 | 0.133 |
| CV | 27.018 | 25.779 | 26.203 |
| Economic sustainability index | | | |
| Mean | 0.266 | 0.278 | 0.336 |
| Minimum | 0.168 | 0.174 | 0.164 |
| Maximum | 0.479 | 0.527 | 0.538 |
| Standard Deviation | 0.080 | 0.084 | 0.086 |
| CV | 29.947 | 30.208 | 25.607 |
| Social sustainability index | | | |
| Mean | 0.408 | 0.504 | 0.579 |
| Minimum | 0.262 | 0.328 | 0.382 |
| Maximum | 0.670 | 0.750 | 0.789 |
| Standard Deviation | 0.093 | 0.102 | 0.102 |
| CV | 22.855 | 20.336 | 17.605 |
| Agricultural sustainability index | | | |
| Mean | 0.395 | 0.432 | 0.474 |
| Minimum | 0.324 | 0.326 | 0.380 |
| Maximum | 0.494 | 0.570 | 0.624 |
| Standard Deviation | 0.056 | 0.065 | 0.061 |
| CV | 14.277 | 15.037 | 12.845 |

State-level policies are the critical factors which affect the environment. Agriculture being a state-subject in India, the states have a major say in policy matters. The major variables considered in the analysis, viz., forests, water usage, livestock, and usage of chemicals in agriculture, are determined more by the state than by the Union Government.

Overall, the environmental sustainability showed a reduction in variability as shown by the CV.

3.4.2. Economic Sustainability

The mean, minimum, and maximum of the economic sustainability index increased during 1991–2011, except for a slight dip in the minimum value in 2001–2011. The CV of the economic sustainability values, which remained around 30% during 1991 and 2001, reduced to 26% by 2011, pointing to a convergence in economic performance among the states (Table 2).

Between 1991 and 2011, economic sustainability improved in all the states except Assam, Bihar, and Jammu and Kashmir (Table S7). In 2011, Punjab, Haryana, and Himachal Pradesh registered the higher economic sustainability in that order, whereas Bihar, Madhya Pradesh, and Rajasthan were at the lower positions. Punjab remained at the top all through, probably due to the high value of output per land, per capita foodgrain production, net irrigated area, and road density. Haryana moved to the second position during 2001 and retained it in the subsequent period. The fast improvement in economic performance of Gujarat (from 15th in 1991 to 7th position in 2011) could be due to high growth in value of output per cropped area and fertilizer usage and improvement in irrigation. West Bengal improved its position from 10th in 1991 to 7th position in 2001, and further to 6th position in 2011 due to faster growth of land productivity and low energy usage. Odisha declined to 13th from 5th position, despite gaining 0.014 index points. Gujarat, Haryana, and Himachal Pradesh, in that order, gained the most in terms of index values during 1991–2011.

Overall, the results indicated an improvement in the economic performance of Indian agriculture over the years. One major reason for this could be the improvement in the productivity of Indian agriculture, in terms of land, energy, and other factors. The TFP in Indian agriculture is growing, albeit with variations among crops and regions [66], and the less productive states are catching up. Investment in the agricultural research and development (R&D) system by the National Agricultural Research and Education System (NARES) is a critical factor for improving agricultural productivity [62,67]. Other major factors are investment in infrastructure including transportation and tele-communication, social capital including education and health care, and the vast extension system [66]. The private investments in agriculture also gained momentum in magnitude and rates of growth starting in the year 2000 [68].

3.4.3. Social Sustainability Index

The progress in environmental and economic indices was expected to lead to social development. The social sustainability index has improved, with consistent reduction in CV. The mean values have improved from 0.408 in 1991 to 0.504 in 2001, and further to 0.579 in 2011 (Table 2). Improvements are also noted in minimum and maximum values. The social sustainability indices have improved for all the states (Table S8).

In 2011, Kerala topped the list with an index value of 0.789, followed by Himachal Pradesh (0.749) and Tamil Nadu (0.709). At the lowest rung were Uttar Pradesh, Bihar, and Madhya Pradesh. Kerala could maintain its position at the highest level mainly on account of high literacy, low poverty rate, and low infant mortality rate, despite registering an increase in income inequality. The "Kerala Model" of economic development is unique in its approach and involves active participation of the masses [69]. It visualises social development through deliberate actions and state interventions, even with a low per capita income. Democratic decentralisation of planning, financial devolution to the local self-government institutions, people's participation in project design and beneficiary identification, and effective utilisation of public sector for universal education, health, and social welfare are quintessential parts of that model [70]. Such an approach could supplement the "trickle down" effect of economic development rather than leaving the economic development to market forces alone. Tamil Nadu also has achieved high educational and health outcomes, with a relatively high growth in per capita income. The data point to a disconnect in translating economic gains to social outcomes in many states. All the states in Peninsular India and Hill Regions (Himachal Pradesh and Jammu and Kashmir) have improved social sustainability considerably, compared to others. Further, states which were relatively smaller in terms of population and geographical area generally performed better in social sustainability.

#### 3.4.4. Agricultural Sustainability Index

The mean ASI has improved from 0.395 in 1991 to 0.474 in 2011 (Table 2). Consistent improvements are noted in the minimum and maximum values. The CV of the index also reduced from 1991 to 2011, except for a slight rise in 2001. Agricultural sustainability was found to increase in all the states (Table S9), and it was the highest in Himachal Pradesh, followed by Jammu and Kashmir and Kerala. These three states performed well in all three dimensions, except Kerala going backwards in environmental sustainability. During 1991–2011, Himachal Pradesh, Tamil Nadu, and Andhra Pradesh recorded the highest improvement in sustainability index points. The marginal gains in the index points at higher absolute values of the index come with increasing marginal efforts. There are several states which slipped from their positions, viz., Assam, Bihar, Gujarat, Karnataka, Madhya Pradesh, and Punjab. The agricultural sustainability was lower in Bihar, Uttar Pradesh, and Gujarat, mainly due to low social and economic sustainability.

One reason for the reduced performance of some states is the failure in attaining social improvements commensurate with gains in economic status. Several reasons could be attributed to this. First, the foremost one is the overarching belief in the efficacy of the trickling down effect. However, those states with deliberate/targeted policies towards improving social welfare fared better. Second, the state level agro-ecology also contributed significantly. For example, those states with diversification towards high value crops and high cropping intensity have bettered in economic sustainability. Third, the states that are endowed with quality environmental assets and the initiatives to protect them have gained significantly in environmental sustainability index. For example, while Jammu and Kashmir and Himachal Pradesh performed better in environmental sustainability index, Kerala slipped to the 12th position in 2011, and its environmental index was declining, which affected the state's overall agricultural sustainability index. The movement of the states with respect to agricultural sustainability over the years is provided in Figure 3. The agricultural sustainability of the states along with the environmental, economic, and social dimensions for the latest year 2011 is provided in Figure 4.

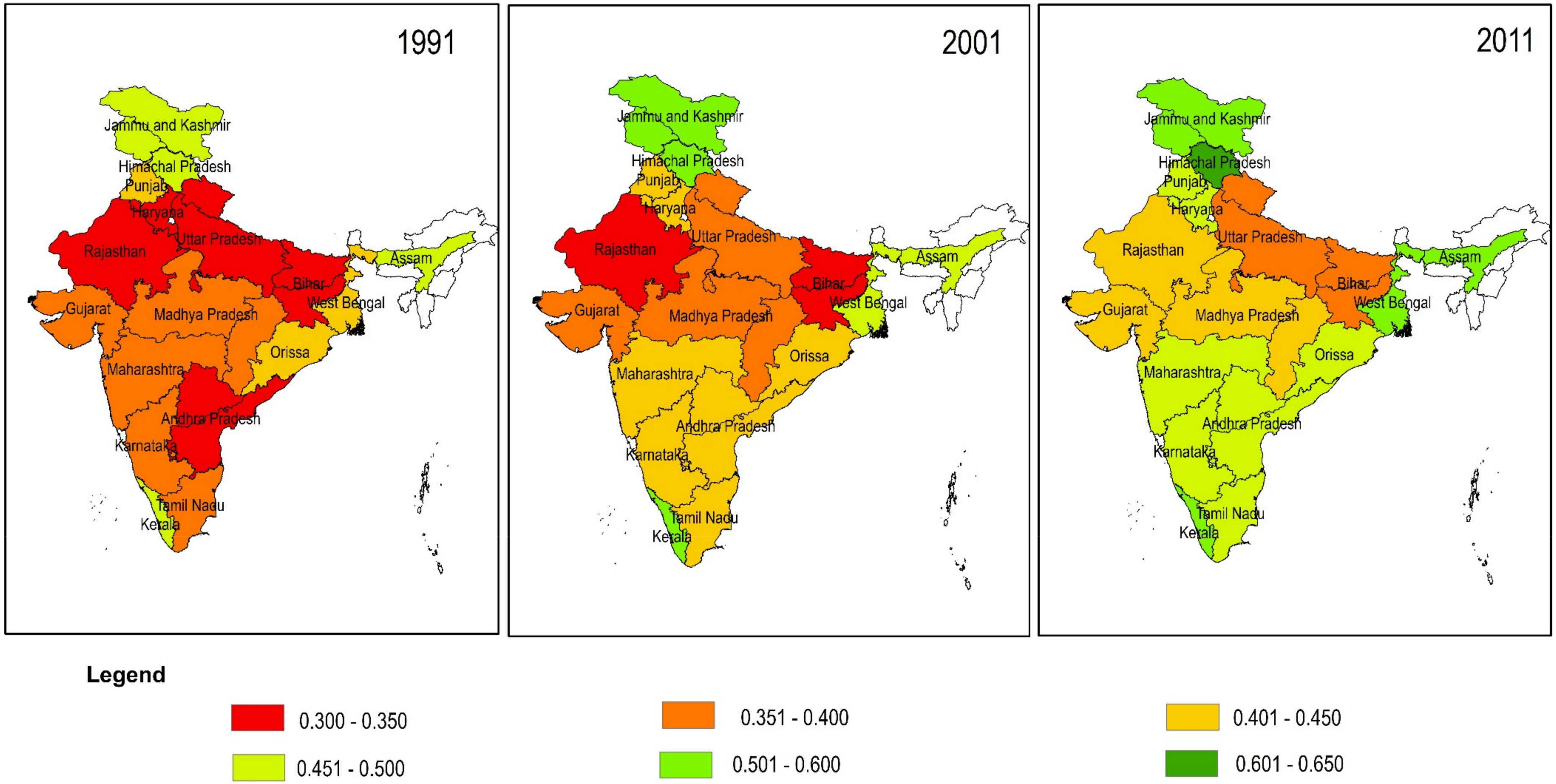


**Figure 3.** Decadal changes in the agricultural sustainability index.

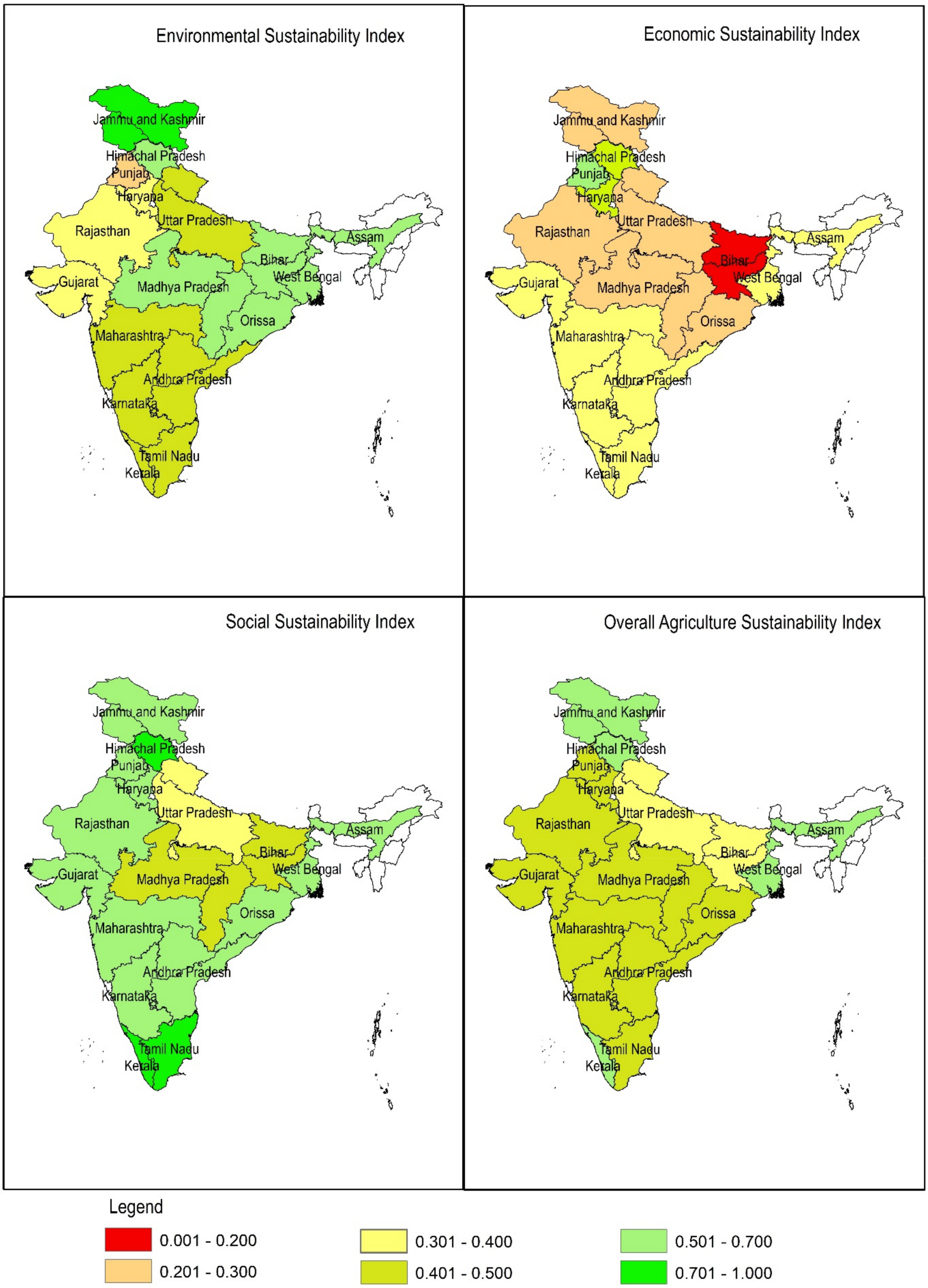


**Figure 4.** Variations in the dimensions of sustainability indices and overall agricultural sustainability index during 2011.

### 3.5. Distribution of States as per the Quartiles

The states were classified into four quartiles based on the levels of the sustainability indices for the year 1991 and 2011, the results of which indicated some interesting patterns (Table 3). In the case of environmental sustainability, Tamil Nadu moved out from the first quartile to the second quartile, and Maharashtra moved from the second to third quartile. However, West Bengal slipped to the third quartile, Uttar Pradesh from the third to second quartile, and Rajasthan from the second to first quartile. The other states were stable at their respective quartile positions. The shift in quartile position of states was sharper in case of economic sustainability. Gujarat moved from the first quartile to the third quartile. Karnataka, Andhra Pradesh, West Bengal, Himachal Pradesh, and Kerala moved one quartile ahead. On the other hand, Jammu and Kashmir slipped from the fourth to first quartile, which was the sharpest movement among all the states across all the indices. The states of Rajasthan, Uttar Pradesh, and Odisha slipped in their positions, with Odisha slipping from the fourth to second quintile. In the case of social sustainability, Rajasthan leapfrogged from the first to third quartile and Andhra Pradesh from the second to fourth quartile. Jammu and Kashmir moved ahead to the third quartile despite a sharp slip in the economic sustainability index. Gujarat and Punjab slipped in their quartile positions. The overall agricultural sustainability index indicated a forward movement of Haryana, Andhra Pradesh, and Maharashtra to the next quartiles, while Gujarat, Madhya Pradesh, and Punjab slipped from their quartile positions. There was no change among the states which were in the fourth quartile.

**Table 3.** Distribution of states in quintiles during 1991 and 2011 according to levels of sustainability.

| Dimension | 1991 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 1st | 2nd | 3rd | 4th |
| Environmental | GJ, HR, PB, TN | AP, KL, MH,RJ | BR, KA, UP | AS, HP, JK, MP, OR, WB | GJ, HR, PB,RJ | AP,KL,TN,UP | BR,KA,MH,WB | AS,HP, JK,MP,OR |
| Economic | BR,GJ,KA,MP | AP,MH,RJ,WB | HP,KL, TN,UP | AS,HR,JK,OR,PB | BR,JK, MP,RJ | KA,MH,OR,UP | AP,GJ, TN,WB | AS,HR, HP,KL,PB |
| Social | BR,MP, RJ,UP | AP,HR, JK,OR | AS,KA, PB,WB | GJ,HP,KL,MH,TN | BR,GJ, MP,UP | AS,HR,OR,PB | JK,KA, RJ,WB | AP,HP,KL,MH,TN |
| Agriculture | BR,HR,RJ,UP | AP,GJ, MH,TN | KA,MP,OR,PB | AS,HP,JK,KL,WB | BR,GJ, RJ,UP | HR,KA,MP,PB | AP, MH, OR,TN | AS, HP, JK,KL,WB |

AP-Andhra Pradesh, AS-Assam, Br-Bihar, GJ-Gujarat, HR-Haryana, HP-Himachal Pradesh, JK-Jammu and Kashmir, KA-Karnataka, KL-Kerala, MP-Madhya Pradesh, MH-Maharashtra, OR-Odisha, PB-Punjab, RJ-Rajasthan, TN-Tamil Nadu, UP-Uttar Pradesh, WB-West Bengal.

### 3.6. Correlation among the Dimensions of Sustainability

The movement of correlation coefficient among the three indices over the years indicated trade-off between the environmental sustainability index and economic sustainability index, and the correlation coefficient got strengthened over the years (Table 4). It moved from −0.12 in 1991 to −0.38 in 2011. The correlation between the economic sustainability index and social sustainability index depicted a complementary relation, which also got strengthened over the years from 0.02 in 1991 to 0.33 in 2011. The relationship between the environment and social sustainability did not have a definite pattern.

**Table 4.** Correlation coefficient among dimensions of sustainability index.

| Year | Env*Eco | Env*Soc | Eco*Soc |
|---|---|---|---|
| 1991 | –0.12 | –0.12 | 0.02 |
| 2001 | –0.34 | 0.23 | 0.25 |
| 2011 | –0.38 | 0.03 | 0.33 |

## 4. Conclusions

Assessing agricultural sustainability at a large geographical level has certain advantages over the approach at the farm level, as it is of policy relevance. The use of indicators for assessing the sustainability, for which data are reported by the Statistical Office of the States and Central Government, make the approach more robust and scalable.

The study provides a potentially useful tool to make decisions, frame public policy, and take governance decisions. The results have a few limitations, viz., (a) not capturing the farm-level impacts, (b) not taking into account more nuanced physical, chemical, and biological characteristics of agricultural systems, and (c) not able to use a continuous set of data so as to understand the time-series nature of progress in sustainability.

The salient conclusions of the study are:

1. Agricultural sustainability: the study constructed indices of environmental, economic, and social dimensions of agricultural sustainability for 17 states and, finally, aggregated them. Eight variables for each dimension, with equal weightage, were used in the study. During 1991–2011, values of agricultural sustainability indices improved in all the states. Negative changes were recorded by nine states for environmental dimension, three States for economic dimension, and no states for social dimension. The movement sf the sustainability index shows that the states of Himachal Pradesh, Jammu and Kashmir, and Kerala are on top of the list. All three states performed well in environment, economic, and social dimensions, except a low performance of Jammu and Kashmir in economic dimensions and Kerala in environmental dimensions. The relative lag in the social front has led states like Bihar, Uttar Pradesh, and Gujarat to their low performance in the overall agricultural sustainability index. Bihar and Uttar Pradesh are highly populated too.
2. Among the component indices, sharp deterioration of environmental quality was noted for Punjab, Haryana, and in other IGP states, which are 'cereal baskets' of India. In economic sustainability, Punjab and Haryana topped the list, which clearly points to the trade-off between the economic gains and environmental quality. However, the positive point is that, compared to 1991–2001, the environmental sustainability index improved during 2001–2011 in more states, which could be attributed to the deliberate effort to conserve the environmental quality while making progress in economic dimension.
3. All the states posted positive changes in the index value in social dimension, unlike in environment and economic dimensions, and had the lowest CV. The social sustainability index did not show significant ($p < 0.05$) correlation with the economic sustainability index. Experience showed that the trickledown effect of economic growth must be supplemented with policies for social development through a targeted approach, in order to have the desirable outcome.
4. For many states, the issues are location-specific, and strategies need to be developed depending on the social and economic fabric of that state, with due consideration for natural resources. Given the interdependency, economic benefits at the cost of environmental quality and social gains would hamper the sustainability of the entire system. It requires policy interventions with location-specific action plans in the agriculture sector to attain overall sustainable development goals.
5. The analysis points to the need for giving weightage to social costs and benefits while formulating agricultural policies, which could be the first step in directing towards a sustainable agricultural system. At ground level, a practical step is assessing changes in ecosystem services, while undertaking developmental projects. This is to be coupled with efforts to improve the productivity of agriculture to gain economic sustainability and deliberate steps to channelize the economic gain to social development. As a future strategy, development and usage of agricultural sustainability index for lesser geographical areas would be useful for micro-level agricultural planning purposes.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14052540/s1, Table S1: Trend in fertilizer use (NPK/ha) and fertilizer use imbalance in India, across States, 1991–2011; Table S2: Trend in net irrigated area and stage of groundwater development in India, across states, 1991–2011; Table S3: Trend in value of output and per capita foodgrain production, across states, 1991–2011; Table S4: Trend in per capita income, rural poverty and inequality; Table S5: Trend in rural non-farm employment and work participation rate; Table S6: Environmental sustainability index, 1991–2011; Table S7: Economic sustainability index, 1991–2011; Table S8: Social sustainability index, 1991–2011; Table S9: Agricultural sustainability index, 1991–2011.

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## References

1. United Nations. Take Action for the Sustainable Development Goals. 2021. Available online: http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed on 4 February 2022).
2. Pretty, J. Agricultural sustainability: Concepts, principles and evidence. *Philos. Trans. R. Soc. Lond. Ser. B* **2008**, *363*, 447–465. [CrossRef] [PubMed]
3. Tilman, D.; Cassman, K.G.; Matson, P.; Naylor, R.; Polasky, S. Agricultural sustainability and intensive production practices. *Science* **2002**, *418*, 671–676. [CrossRef] [PubMed]
4. Lal, R. Soil structure and sustainability. *J. Sustain. Agric.* **1991**, *1*, 67–91. [CrossRef]
5. Rigby, D.; Caceres, D. Organic farming and the sustainability of agricultural system. *Agric. Syst.* **2001**, *68*, 21–40. [CrossRef]
6. Velten, S.; Leventon, J.; Jager, N.; Newig, J. What Is Sustainable Agriculture? A Systematic Review. *Sustainability* **2015**, *7*, 7833–7865. [CrossRef]
7. Grossman, G.; Krueger, A. Environmental Impacts of a North American Free Trade Agreement. In *Environmental Impacts of a North American Free Trade Agreement*; National Bureau of Economic Research: Cambridge, MA, USA, 1991.
8. Grossman, G.M.; Krueger, A.B. Economic Growth and the Environment. *Q. J. Econ.* **1995**, *110*, 353–377. [CrossRef]
9. Kuznets, S. Economic growth and income inequality. *Am. Econ. Rev.* **1955**, *45*, 1–28.
10. Sadik-Zada, E.R.; Ferrari, M. Environmental policy stringency, technical progress and pollution haven hypothesis. *Sustainability* **2020**, *12*, 3880. [CrossRef]
11. Rasul, G.; Thapa, G.B. Sustainability of ecological and conventional agricultural systems in Bangladesh: An assessment based on environmental, economic and social perspectives. *Agric. Syst.* **2004**, *79*, 327–351. [CrossRef]
12. Roy, R.; Chan, N.W. An assessment of agricultural sustainability indicators in Bangladesh: Review and synthesis. *Environmentalist* **2012**, *32*, 99–110. [CrossRef]
13. Saleth, R.M. Agricultural sustainability status of the agroclimatic subzones of India: Empirical illustration of an indexing approach. *Indian J. Agric. Econ.* **1993**, *48*, 543–550.
14. Kareemulla, K.; Venkatakumar, R.; Samuel, M.P. An analysis of agricultural sustainability in India. *Curr. Sci.* **2017**, *112*, 258–266. [CrossRef]
15. Malkina-Pykh, I.G. From data and theory to environmental models and indices formation. *Ecol. Model.* **2000**, *130*, 67–77. [CrossRef]
16. Woodhouse, P.; Howlett, D.; Rigby, D. *A Framework for Research on Sustainability Indicators for Agriculture and Rural Livelihoods, Working Paper 2*; Department of International Development Research: UK, 2000. Available online: https://www.gov.uk/research-for-development-outputs/a-framework-for-research-on-sustainability-indicators-for-agriculture-and-rural-livelihoods-working-paper-2 (accessed on 4 February 2022).
17. Riley, J. Indicator quality for assessment of impact of multidisciplinary systems. *Agric. Ecosyst. Environ.* **2001**, *87*, 121–128. [CrossRef]
18. Rao, N.H.; Rogers, P.P. Assessment of agricultural sustainability. *Curr. Sci.* **2006**, *91*, 439–448.
19. Yigitcanlar, T.; Dur, F.; Dizdaroglu, D. Towards prosperous sustainable cities: A multiscalar urban sustainability assessment approach. *Habitat Int.* **2015**, *45*, 36–46. [CrossRef]
20. Pannell, D.J.; Schilizzi, S. Sustainable Agriculture: A Question of Ecology, Equity, Economic Efficiency or Expedience? *J. Sustain. Agric.* **1999**, *13*, 57–66. [CrossRef]
21. Gómez-Limón, J.A.; Sanchez-Fernandez, G. Empirical evaluation of agricultural sustainability using composite indicators. *Ecol. Econ.* **2010**, *69*, 1062–1075. [CrossRef]

22. Saisana, M.; Tarantola, S. *State of the Art Report on Current Methodologies and Practices for Composite Indicator Development*; European Commission-JRC: Ispra, Italy, 2002.
23. Chand, R.; Pandey, L.M. *Fertilizer Growth, Imbalances and Subsidies: Trends and Implications. Discussion Paper*; National Centre for Agricultural Economics and Policy Research: New Delhi, India, 2008.
24. Pillarisetti, J.R.; van den Bergh, J.C.J.M. *Sustainable Nations: What Do Aggregate Indicators Tell Us? TI 2008-012/3 Tinbergen Institute Discussion Paper*; Tinbergen Institute: Amsterdam, The Netherlands, 2008; Available online: https://papers.tinbergen.nl/08012.pdf (accessed on 4 February 2022).
25. Nambiar, K.K.M.; Gupta, A.P.; Fu, Q.; Li, S. Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. *Agric Ecosyst Environ.* **2001**, *87*, 209–214. [CrossRef]
26. Foley, J.A. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef]
27. Rodrigues, J.L.M.; Pellizari, V.H.; Mueller, R.; Baek, K.; Jesus, E.D.C.; Paula, F.S.; Mirza, B.; Hamaouli, G.H., Jr.; Tsai, S.M.; Feigl, B.; et al. Conversion of the Amazon rainforest to agriculture results in biotic homogenization of soil bacterial communities. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 988–993. [CrossRef] [PubMed]
28. Delang, C.O.; Yuan, Z. *China's Grain for Green Program*; Springer Nature: Berlin/Heidelberg, Germany, 2015.
29. Matson, P.A.; Parton, W.J.; Power, A.G.; Swift, M. Agricultural intensification and ecosystem properties. *Science* **1997**, *277*, 504–509. [CrossRef] [PubMed]
30. Pingali, P.L. Green revolution: Impacts, limits, and the path ahead. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 12302–12308. [CrossRef] [PubMed]
31. Sun, B.; Zhang, L.X.; Yang, L.Z.; Zhang, F.S.; Norse, D.; Zhu, Z.L. Agricultural non-point source pollution in China: Causes and mitigation measures. *Ambio* **2012**, *41*, 370–379. [CrossRef]
32. MacDonald, G.K.; Bennett, E.M.; Potter, P.A.; Ramankutty, N. From the cover: Agronomic phosphorus imbalances across the world's croplands. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 3086–3091. [CrossRef]
33. Henry, M.; Beguin, M.; Requier, F.; Rollin, O.; Odoux, J.-F.; Pierrick, A.; Aptel, J.; Tchamitchian, S.; Decourtyes, A. A common pesticide decreases foraging success and survival in honey bees. *Science* **2012**, *336*, 348–350. [CrossRef]
34. Suresh, A.; Aditya, K.S.; Jha, G.; Pal, S. Micro-irrigation development in India: An analysis of distributional pattern and potential correlates. *Int. J. Water Resour. Dev.* **2019**, *35*, 999–1014. [CrossRef]
35. Shah, T. *Taming the Anarchy: Groundwater Governance in South Asia*; Routledge: Oxfordshire, UK, 2010.
36. Russelle, M.P.; Entz, M.Z.; Franzluebbers, A.J. Reconsidering integrated crop–livestock systems in North America. *Agron. J.* **2014**, *99*, 325–334. [CrossRef]
37. Salton, J.C.; Mercante, F.M.; Tomazi, M.; Zanatta, J.A.; Concenço, G.; Silva, W.M.; Retore, M. Integrated crop-livestock system in tropical Brazil: Towards a sustainable production system. *Agric. Ecosyst. Environ.* **2014**, *190*, 70–79. [CrossRef]
38. Nicholson, S.E. Climatic and environmental change in Africa during the last two centuries. *Clim. Res.* **2001**, *17*, 123–144. [CrossRef]
39. Kurukulasuriya, P.; Rosenthal, S. *Climate Change and Agriculture: A Review of Impacts and Adaptations*; World Bank: Washington, DC, USA, 2013.
40. Gadgil, S.; Gadgil, S. The Indian monsoon, GDP and agriculture. *Econ. Political Wkly.* **2006**, *41*, 4887–4895.
41. Viswanathan, B.; Kavikumar, K.A. *Weather Variability, Agriculture and Rural Migration: Evidence from State and District Level Migration in India*; South Asian Network for Development and Environmental Economics (SANDEE): Kathmandu, Nepal, 2014.
42. Cassman, K.G. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. USA* **1999**, *96*, 5952–5959. [CrossRef]
43. Sharma, H.R. Agricultural development and crop diversification in Himachal Pradesh: Understanding the patterns, processes, determinants and lessons. *Indian J. Agric. Econ.* **2005**, *60*, 71–93.
44. Sha, T.; Gulati, A.; Hemant, P.; Sreedhar, G.; Jain, R.C. Secret of Gujarat's agrarian miracle after 2000. *Econ. Political Wkly.* **2009**, *54*, 45–55.
45. Suresh, A.; Ramasundaram, P.; Samuel, J.; Wankhade, S. Cotton cultivation in India since the green revolution: Technology, policy, and performance. *Rev. Agrar. Stud.* **2014**, *4*, 26–52.
46. Chand, R.; Raju, S.S. Instability in Indian agriculture during different phases of technology and policy. *Indian J. Agric. Econ.* **2009**, *64*, 187–207.
47. Boserup, E. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*; Aldine Pub. Co.: New York, NY, USA, 1965.
48. Suresh, A. Efficiency of agricultural production in India: An analysis using non-parametric approach. *Indian J. Agric. Econ.* **2015**, *70*, 471–486.
49. Jayne, T.S.; Yamano, T.; Weber, M.T.; Tschirley, D.; Benfica, R.; Chapota, A.; Zulu, B. Smallholder income and land distribution in Africa: Implications for poverty reduction strategies. *Food Policy* **2003**, *28*, 253–275. [CrossRef]
50. Scherr, S.J. A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy* **2000**, *25*, 479–498. [CrossRef]
51. Hazell, P.; Thorat, S.K.; Fan, S.S. Impact of public expenditure on poverty in rural India. *Econ. Political Wkly.* **2000**, *35*, 3581–3588.
52. Bathla, S.; Thorat, S.K.; Joshi, P.K.; Yu, B. Where to invest to accelerate agricultural growth and poverty reduction. *Econ. Political Wkly.* **2017**, *52*, 10.

53. Sadik-Zada, E.R.; Loewenstein, W. A Note on Revenue Distribution Patterns and Rent Seeking Incentive. *Int. J. Dev. Res.* **2018**, *8*, 95–102.
54. Ghosh, P.P.; Gupta, C.D. *Uneven Growth in India—Inter- and Intra-State Disparities*; Manak Publications Pvt. Ltd.: New Delhi, India, 2017.
55. Kumar, A. Dynamics of access to rural credit in India: Patterns and determinants. *Agric. Econ. Res. Rev.* **2015**, *28*, 151–166. [CrossRef]
56. Azam, M.; Shariff, A. Income inequality in rural India: Decomposing the Gini by income sources. *Econ. Bull.* **2011**, *31*, 739–748.
57. Ruttan, V.W. *Sustainable Agriculture and the Environment: Perspectives on Growth Constraints*; Westview Press: Boulder, CO, USA, 1992.
58. Reserve Bank of India. 2019. Report of the Internal Working Group to Review Agricultural Credit. Available online: https://rbidocs.rbi.org.in/rdocs//PublicationReport/Pdfs/WGREPORT101A17FBDC144237BD114BF2D01FF9C9.PDF (accessed on 4 January 2020).
59. Alesina, A.; Giuliano, P.; Nunn, N. Traditional agricultural practices and the sex ratio today. *PLoS ONE* **2018**, *13*, e0190510. Available online: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0190510 (accessed on 4 January 2020). [CrossRef]
60. Agnihotri, S.B. *Sex Ratio Pattern of Indian Population—A Fresh Exploration*; SAGE Publications Pvt. Ltd.: New Delhi, India, 2000.
61. Block, S.; Webb, P. The dynamics of livelihood diversification in post-famine Ethiopia. *Food Policy* **2001**, *26*, 333–350. [CrossRef]
62. de Janvry, A.; Elisabeth, S.; Nong, Z. *The Role of Non-Farm Incomes in Reducing Rural Poverty and Inequality in China, CUDARE Working Paper*; University of Berkeley: Berkeley, CA, USA, 2005; Available online: https://escholarship.org/uc/item/7ts2z766 (accessed on 4 January 2020).
63. Sadik-Zada, E.R.; Loewenstein, W.; Hasanli, Y. Commodity Revenues, Agricultural Sector and the Magnitude of Deindustrialization: A Novel Multisector Perspective. *Economies* **2019**, *7*, 113. [CrossRef]
64. Reardon, T.; Crawford, E.; Kelly, V. Links between non-farm income and farm investment in African households: Adding the capital market perspective. *Am. J. Agric. Econ.* **1994**, *76*, 1172–1176. [CrossRef]
65. Lewis, W.A. *The Theory of Economic Growth*; Taylor and Francis: London, UK, 2003.
66. Chand, R.; Praduman, K.; Sant, K. Total factor productivity and returns to public investment on agricultural research in India. *Agric. Econ. Res. Rev.* **2012**, *25*, 181–194.
67. Evenson, R.E.; Pray, C.E.; Rosegrant, M.W. *Agricultural Research and Productivity Growth in India*; International Food Policy Research Institute: Washington, DC, USA, 1999.
68. Kumar, A.; Bathla, S.; Verma, S. *Changing Composition of Private Investment in Indian Agriculture and its Relationship with Public Investment and Input Subsidies*; IFPRI Discussion Paper 01905; South Asia Regional Office: New Delhi, India, 2020.
69. Kurien, J. The Kerala Model: Its ccentral ttendency and the ooutlier. *Soc. Sci.* **1995**, *23*, 70–90.
70. Kannan, K.P.; Pillai, V.N. Development as a Right to Freedom: An Interpretation of the Kerala Model, Working Paper 361. Centre for Development Studies, Thiruvananthapuram. 2004. Available online: https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/3065/wp361.pdf?sequence=1&isAllowed=y (accessed on 4 January 2020).