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Abstract

Improving economic viability of Indian agriculture is contingent upon agri-environmental sustainability (AES). For agriculture, environment acts as a sink of pollution load as well as inputs for production. Objective assessment of environmental impacts of Indian agriculture and impacts of polluted environment on agriculture are crucial for AES. The costs of polluted environment on agriculture will be borne by farmers in terms of loss of productivity and quality of farm produces. Comprehensive assessment of economic costs of environment on Indian agriculture is lacking. On the other hand, unless internalize environmental impacts of agriculture will be borne by the society – in terms of depletion and degradation of water resources, land degradation and emissions of GHGs. Environmental impact of agriculture will be largely borne by vulnerable sections of the society who cannot afford to adopt pollution aversion practices (or technologies) to avoid health hazards. Moreover, marginal and small farmers may also not be able to mitigate the impact of polluted environment on their farmland by adopting various coping mechanism (pollution averting behavior). Therefore agri-envirionmental sustainability of Indian agriculture is important for wellbeing of Indian farmers.

In the absence of system of integrated environment and economic accounting (SEEA) in India, present paper builds a comprehensive agri-environmental sustainability index (AESI) based on 40 indicators to assess the potential (possible) impact of agriculture on environment. The study captures both spatial and temporal aspects of AES by covering 17 general category states for the period 1990-91 to 2013-14. The study comes out policy suggestions which could be useful to adopt sustainable agricultural practices.

Key words: agro-ecosystem & environment; agri-environmental sustainability; agri-environmental indicator; sustainable agriculture; environmental sustainability; Indian states.

JEL Classification Codes: Q56, Q15, C00

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1. Introduction

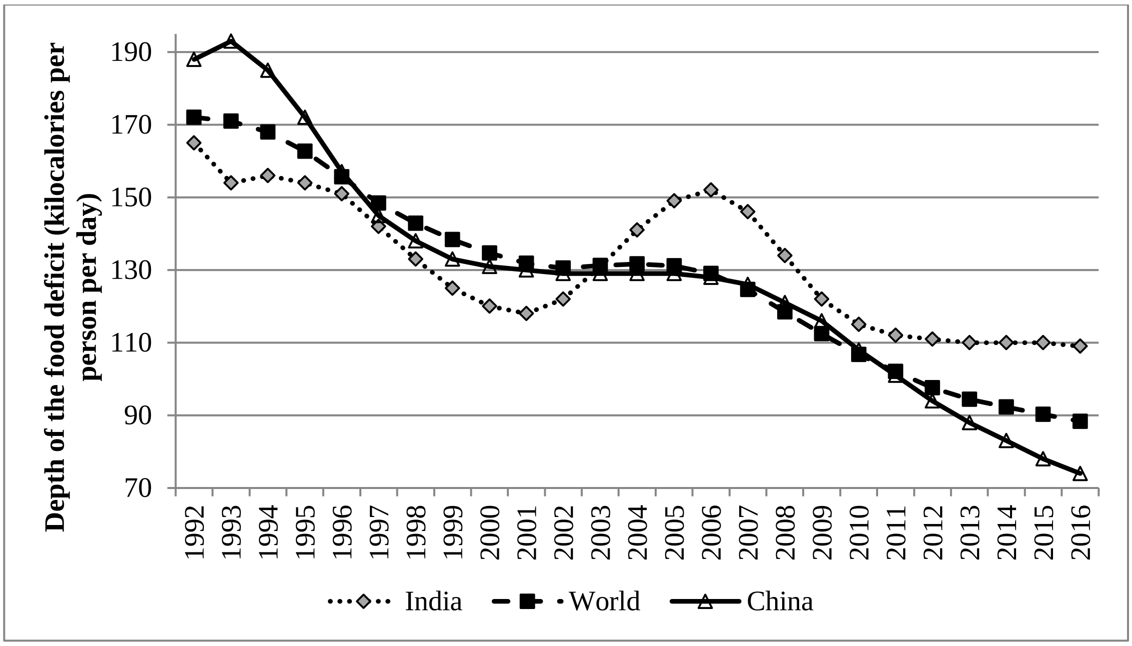
Agricultural sustainability is defined as "when current and future food demands can be met without unnecessarily compromising economic, ecological, and social/political needs then agriculture is considered to be sustainable" (Agricultural Sustainability 2004 as cited in Królczyk and Latawiec 2015). Agricultural sustainability depends on agri-environmental sustainability (AES) (Hayati et al. 2011). In the absence of any system of integrated environment and economic accounting, agri-environmental sustainability index (AESI) could help in understanding the state of environmental sustainability of agriculture for a country/ state. Achieving environmental sustainability of agriculture for developing countries like India is crucial not only to protect the livelihoods of a large section of the populace but also to eradicate poverty and malnutrition. The intensive agricultural practices followed since 1960s has resulted in large scale degradation of soil, conversion of forest land, depletion and degradation of groundwater, diversions of surface water and loss of biodiversity (Shah 2012). Agriculture touches upon all spheres of environment and natural resources (land, water and air) to source inputs and dispose wastes as sink. Agricultural sustainability is largely depended on sustainability of natural resources (like land and water) as well as ecosystem services. Deteriorating water environment, land degradation and growing demand for land from alternative uses are the major challenges that Indian agriculture is facing today. Though agriculture is the major user of water, demand for diversion of water for alternative uses is rising with rise in population, urbanization, per capita income and unavailability of local sources of water. Large scale depletion and degradation of water resources is observed in various parts of India. Deteriorating soil fertility and rising cost of accessing reliable sources of irrigation water are the major factors influencing the rising cost of agriculture (Mukherjee 2012).

High importance of water and chemical intensive crops (like paddy, sugarcane and cotton) in cropping pattern and adoption of unsustainable irrigation practices reduce capacity of Indian agriculture to withstand shocks like droughts. Rising input intensity (water, fertilizers, pesticides, energy and farm machinery) increases costs of cultivation whereas farm produce prices are not always remunerative for farmers. Moreover, increasing incidence of crop failures due to natural disasters and pests attack make farmers' income volatile. The imbalance between costs of cultivation and farmers' income from agriculture make farmers' indebted. Recurrent crops failures and/ or not receiving remunerative prices of crops make farmers' livelihoods unsustainable. Due to this a large numbers of small and marginal farmers compel to leave agriculture all together and look for alternative employments elsewhere. Therefore achieving agri-environmental sustainability could help India to overcome ongoing agricultural distress.

India is reeling under high food deficit (as measured by average calorie intake and average minimum dietary energy requirements) and to achieve food security equitable distribution of foods is as important as increasing food production. According to a recent study about 472 million people in India, a staggering 39 percent of the population, are undernourished in 2011–12 (Rawal et al. 2019). The depth of food deficit (as measured by kilocalorie per person per day) in India was lower than world's average and that of

China till 2002 (Figure 1).[1] During 2003 to 2006, the food deficit has increased in India and it was higher than world's average and that of China. Since 2007, a declining trend in food deficit is observed for India till 2012 and thereafter it remains constant at 130 kilocalories per person per day. Except Sub-Saharan Africa and South Asia, the depth of food deficit in India is worse than other continents (Table 1). Though India contributes considerable share in world's food production, prevalence of malnutrition in India is severe.[2] To achieve food security for all, India needs to produce more foods as well as to take measures in equitable distribution of foods for all.

Figure 1: Depth of the Food Deficit in India vis-à-vis China and World's Average



Source: World Bank's World Development Indicator Database

In Global Hunger Index (GHI) of 2017, India's rank is 100th among 119 countries considered by International Food Policy Research Institute (IFPRI) for ranking. IFPRI classifies the GHI score into five categories - extremely alarming (≥50.0), alarming (35.0-49.9), serious (20.0-34.9), moderate (10.0-19.9) and low (≤9.9). India's score falls under 'serious category'. As compared to neighboring countries in South Asia and Southeast Asia, India is a laggard in GHI. Even immediate neighbors like Bangladesh, Sri Lanka and Nepal are better placed in GHI as compared to India (Table 2). Among BRICS countries, India stands out and sustained effort is required to catch up with other BRICS countries. Therefore sustainable availability of food is very important for India to overcome the persisting large scale hunger and malnutrition.

[1] The depth of the food deficit indicates how many calories would be needed to lift the undernourished from their status, everything else being constant. The average intensity of food deprivation of the undernourished, estimated as the difference between the average dietary energy requirement and the average dietary energy consumption of the undernourished population (food-deprived), is multiplied by the number of undernourished to provide an estimate of the total food deficit in the country, which is then normalized by the total population. (Food and Agriculture Organization, Food Security Statistics.)

[2] In 2016, India contributed 10.3 percent of world's total cereal production, 21.5 percent of total pulses production and 3.1 percent of world's total coarse grain production (FAO Stat 2018).

Table 1: Depth of the food deficit (kilocalories per person per day)

Country/ Continent	1995	2000	2005	2010	2016
East Asia & Pacific	175	140	132	107	74
Latin America & Caribbean	99	92	69	50	40
Middle East & North Africa	50	54	59	59	47
South Asia	170	136	153	122	118
Sub-Saharan Africa	240	210	180	151	130
World	163	135	131	107	88
Bangladesh	277	189	118	119	116
Brazil	105	97	42	17	10
China	172	131	129	108	74
India	154	120	149	115	109

Data Source: Constructed from World Bank's World Development Indicator Database

Table 2: Global Hunger Index*

Country	1992 (1990-94)	2000 (1998-2002)	2008 (2006-10)	2017 (2012-16)	
				Score	Rank
Afghanistan	50.2	52.7	37.9	33.3	107
Bangladesh	53.6	37.6	32.2	26.5	88
Brazil	15.9	11.7	5.4	5.4	18
China	25.9	15.8	11.2	7.5	29
India	46.2	38.2	35.6	31.4	100
Indonesia	35.0	25.5	28.3	22.0	72
Lao PDR	52.3	48.1	33.4	27.5	91
Malaysia	19.8	15.5	13.7	10.2	44
Myanmar	55.6	43.6	30.1	22.6	77
Nepal	42.5	36.8	28.9	22.0	72
Pakistan	42.7	38.2	34.7	32.6	106
Philippines	30.5	25.9	20.2	20.0	68
Russian Federation	-	10.5	6.8	6.2	22
South Africa	18.5	18.8	16.6	13.2	55
Sri Lanka	31.6	26.8	24.2	25.5	84
Thailand	25.8	18.1	12.0	10.6	46
Vietnam	40.2	28.6	21.6	16.0	64
Central African Republic	52.2	50.9	47.0	50.9	119

Note: *-IFPRI considers four indicators, viz., proportion of the population that is undernourished (in %) (PUN), prevalence of wasting in children under five years old (in %) (CWA), prevalence of stunting in children under five years old (in %) (CST), and proportion of children dying before the age of five (in %) (CM), in constructing the GHI. For detailed methodology see page no. 32 of the Report (von Grebmer et al. 2017).

Given the importance of agri-environmental sustainability (AES), United Nations set the Target 2.4 under the Sustainable Development Goals (SDGs) and it is as follows:

> **Target 2.4:** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality[3]

To assist countries to assess the achievement in SDG target 2.4, FAO has come out with a draft list of agri-environmental indicators (AEIs) for discussion (FAO 2017). However, many targets set under SDGs are affected by AES and also AES is affected by many other targets. Therefore to understand the importance of AES, we present a comprehensive list of such SDG goals, their targets and underlying indicators in Appendix I.

In the absence of comprehensive system of integrated environmental and economic accounting in India, assessment based on AESI could help policy makers to assess the present state of environmental sustainability of Indian agriculture. Given the union government's initiative to lunch "National Mission for Sustainable Agriculture", development of a comprehensive AESI for India could help to focus on issues related to long-run agricultural as well as environmental sustainability. Moreover, AESI could also help to assess the present state of AES across Indian states and devise state-specific policies and programmes to meet the SDG target 2.4. There are many co-benefits of AES and those are highlighted in Appendix I.

In the next section we review literature which develops AEIs to assess AES. In section 3, we present our methodology and data sources and in section 4 we present our results. In section 5, we validate our results with various indicators of environmental impacts of agriculture. We draw our conclusions in section 6.

2. Literature Review

There is a wide range of literature on development of agri-environmental index (AEI) that has been evolved over the last two decades. The existing studies on AEI could be classified into two broad categories – a) macro or indicator based analysis of environmental impacts of agriculture (e.g., Binder et al. 2010, Girardin et al. 2000, Hajkowicz et al. 2008) and b) field level experiments (either based on simulations or model based analysis, experiments - e.g., Bockstaller et al. 2007, Langeveld et al. 2007, van der Werf and Petit 2002). In this paper, we focus on studies which assess the overall status

[3] Available at: https://sustainabledevelopment.un.org/sdg2 (last accessed on 19 July 2019).

of AES based on indicators. The effectiveness of AEIs can be judged from their quantifiability, scientific soundness, reference to relevant issues and cost effectiveness.

The OECD Compendium of AEIs provides a set of 18 AEIs across 34 OECD countries from 1990 to 2010 (OECD 2013) (Table 3). The study describes the current state of agriculture, changes over the time (1990 to 2010) and its environmental impacts in OECD countries. Many of the indicators identified by the OECD are not available for Indian states and given the local condition and variability in dimensions of AES, list of indicators to assess AES may change (OECD 2013).

Table 3: Coverage of Agri-Environmental indicators in the OECD Study

Theme	Indicator Title	Indicator Definition
I. Soil	Soil erosion	1. Agricultural land affected by water and wind erosion, classified as having moderate to severe water and wind erosion risk
II. Water	Water resources	2. Agriculture freshwater withdrawals 3. Irrigated land area 4. Irrigation water application rate – megalitres of water applied per hectare of irrigation land
	Water quality	5. Nitrate, phosphorous and pesticide pollution derived from agriculture in surface water, groundwater and marine waters
III. Air and climate change	Ammonia	6. Agriculture ammonia emissions
	Greenhouse gases	7. Gross total agricultural greenhouse gas emissions (methane and nitrous oxide, but excluding carbon dioxide)
	Methyl bromide	8. Methyl bromide use, expressed in tonnes of ozone depleting substances equivalents
IV. Biodiversity	Farmland birds	9. Populations of a selected group of breeding bird species that are dependent on agricultural land for nesting or breeding
	Agricultural land cover	10. Agricultural land cover types - arable crops, permanent crops and pasture areas
V. Agricultural inputs and outputs	Production	11. Agricultural production volume – index of change in total agriculture, crop and livestock production
	Nutrients	12. Gross agricultural nitrogen and phosphorous balances, surplus or deficit
	Pesticides	13. Pesticide sales, in tonnes of active ingredients
	Energy	14. Direct on-farm energy consumption 15. Biofuel production to produce bioethanol and biodiesel from agricultural feedstocks
	Land	16. Agricultural land use area 17. Certified organic farming area 18. Transgenic crop area

Source: OECD (2013, Annex 1.A1, Page No. 34)

The list of OECD's indicators evolved over the years. For instance, OECD presented a list of 37 indicators in its 2008 report (OECD 2008, ANNEX II.A1, page 29-30). In the 6th session of the Conference of European Statistics, the Committee on Environmental Policy reviewed a selected list of indicators which emphasizes on the importance of quantitative information on agri-environmental linkages. The IRENA[4] operation was conducted and the European Commission identified 28 environmental indicators that are still being maintained and developed (EEA 2006, UNECE 2012). AEI has emerged as a major tool for policy making. Various organizations of the United Nations Economic Commission for Europe (UNECE) are preparing AEIs for Eastern Europe, Caucasus and Central Asia. The major indicators were fertilizer consumption, pesticide consumption, irrigation, energy consumption, agricultural land use, cropping and livestock pattern, gross nitrogen balance, agricultural ammonia emission, emission of methane and nitrous oxides and other greenhouse gases, water abstraction, soil erosion and nitrates in water.

Sands and Podmore (2000) has focused on environmental challenges those pose threat to human health, e.g., water depletion and degradation, in developing Environmental Sustainability Index (ESI). ESI quantitatively assesses environmental sustainability using a model and characterize agricultural system. The two axioms presented in the paper are as follows:

> "Axiom 1: An environmentally sustainable agricultural system is one in which the inherent capacity of the soil and water resources that support agricultural production are maintained or improve over time
>
> Axiom 2: An environmentally sustainable agricultural system is one where no leaching, lateral flow and/or runoff of degradative constituents occur."

The two models used in this paper are the EPIC (Erosion Productivity Impact Calculator) Model simulations and the Principle Component Analysis to aggregate 15 sustainability sub-indices and to represent differences in sustainability among the evaluated cropping systems.

Brouwer and Crabtree (1998) has discussed extensive land use system in the Iberian Peninsula. Based on the 1997 framework of OECD and they have used 36 indicators to build an AEI for that region. On analyzing the qualitative relationship between the indicators and its impact on environment, it was divided into positive, negative, hump-shaped. They have focused on spatial continuity of the ecosystem, homogeneity in the process of intensification - extensification and abandonment. The objective of the paper was to develop AEI's to determine the impact of CAP (Common Agricultural Policy) on the environment, for which it suggested a three-stage approach, (i) making an inventory of European agrosystem, (ii) making a list of indicators, (iii) developing a mechanism to collect farms data.

[4] Indicator reporting on the integration of environmental concerns into agriculture policy

Huffman et al. (2000) has used the soil landscape spatial model to address the problems of soil quality degradation for Canada. This paper focuses on land quality indicators and GIS to interpret the intensity of soil degradation using a soil landscape spatial model. The results show that there has been an improvement in soil quality despite expansion of intensive cropping systems due to conservation tillage, crop residue management, reduced summer fallowing and the risk of wind erosion in the Canadian Praires, while the risk of soil salinization is still present in majority of the region.

Hayati et al (2010) discuss about the difficulties in measuring agricultural sustainability. The authors have used system theory to define boundaries of the system under consideration- the cropping system, the farming system, watershed or village, landscape or district. This paper refers to the 'driving force state response' framework that led OECD to identify 39 indicators on issues of farm financial resources, farm management, use of nutrients, pesticides, water, quality of soil, water, agricultural land at present, rural economy, energy, etc. The indicators are selected in formulation of policies that aim at achieving sustainable development. The study concludes that the current measures cannot fully explain the interdependency and trade-off between components. Hayati et al (2010) argues that AES measures may not be much help to farmers if it makes difficult for them to monitor how sustainable agriculture is. They conclude that 'tragedy of commons' or conflicting interests among different hierarchical levels of the system makes sustainable strategy all the more difficult.

Zhen and Routray (2003) presents a list of agricultural indicators pertaining three dimensions (economics, social and ecological/ environmental) of sustainability (Table 4).

Table 4: Proposed Agricultural Indicators for Measuring Sustainability

ECONOMIC	• **Crop productivity**
	• Net farm income
	• Benefit-cost ratio of production
	• Per capita food grain production
SOCIAL	• Food self sufficiency
	• Equality in income and food distribution
	• Access to resources and support services
	• Farmers knowledge and awareness of resource conservation
ECOLOGICAL	• Amount of fertilizers / pesticides used per unit of cropped land
	• Amount of irrigation water used per unit of cropped land
	• Soil nutrient content
	• Depth of groundwater table
	• Quality of groundwater for irrigation
	• Water use efficiency
	• Nitrate content of groundwater and crops

Source: Zhen and Routray (2003)

Eilers et al. (2010) has analyzed the impact of environmental performance of agriculture and the impact of adopting environmentally beneficial policies in Canada. They have divided the indicators by their policy relevance, scientific soundness, understandability, capacity to identify geospatial and temporal change and feasibility; and categorized into risk, state or eco-efficiency indicators. The elements considered to analyze the sustainability condition of agriculture in Canada are farm land management, soil health and water quality, air quality, food and beverage industry and how science and policy have been linked using models. Significant intensification and diversification of agricultural production activities in Canada observed in the paper. Production has shifted from traditional crops like wheat and maize to corn, oilseeds, pulses, etc.

Reytar et al. (2014) has conducted a thorough analysis of the existing indictors, indices and datasets which are usually considered in the environmental sustainability of agriculture. They observed that indicators mostly influence public policy, farmer practice and biophysical performance. This paper aims at communicating to policy makers, farmers and the society to what extent agriculture in being practiced sustainably. The indicators are selected on the basis on their availability, accuracy, consistency, frequency, primacy, relevance and differentiability. Quantitative indicators have immense potential to influence policy makers, farmers, businesses and civil societies to take initiatives to proceed in agricultural growth on sustainable path.

Pretty and Bharucha (2018) has discussed the importance of sustainable intensification in agriculture. The three critical phases of sustainable agriculture are – efficiency, substitution and redesign. They observed that attaining efficiency in agriculture implies reducing the use of fertilizers and pesticides which are capable of impairing natural capital and health of human population. It is of utmost importance that while redesigning agro-ecological processes in the 21st century, we focus on processes like nutrient cycling, biological nitrogen fixation, parasitism, allelopathy, etc. Methods of reducing the impact of externalities in agriculture should be formulated.

Different aspects of AES has been studied extensively for developed countries, however there is very little literature on this subject for developing countries like India. According to our information, there is no study specific to India which builds AEIs to assess the state of AES for Indian states. Earlier Mukherjee and Kathuria (2006) and Mukherjee and Chakraborty (2009) constructed Environmental Quality Index (EQI) for Indian states to assess environmental quality for two time periods 1990–1996 and 1997–2004. These studies build three sub-indices - 'Depletion and degradation of water resources', 'Nonpoint Source Water Pollution Potential' and 'Pressure and degradation of land resources' – which have some bearing with AES. The present study expects to initiate discussion on AES in India.

3. Methodology and Data Sources

Based on literature review and assessment of availability of time series data at State level, we have identified a list of 40 AEIs to measure AES of Indian states. We have classified these indicators into eight groups or sub-indices of AESI and presented in Table 5. These groups constitute the building blocks for constructing AESI. In selecting the indicators we gave emphasis on 'causes' of agri-environmental impacts whereas we have used 'outcome' indicators (e.g., groundwater nitrate pollution, land degradation) to assess the validity of constructed sub-indices. To capture temporal variations of agricultural impacts on environment, we have divided the entire period of our analysis (i.e., 1990-91 to 2013-14) into three sub-periods – 1990s (1990-91 to 1999-2000), 2000s (2000-01 to 2009-10) and 2010s (2010-11 to 2013-14). While 1990s mark the early years of economic liberalization, 2000s mark high economic growth period and 2010s mark the low growth period. To capture spatial variations, we have considered 17 major Indian states. The list of indicators and sub-indices of AESI are provided in the Appendix II.

Each of the indicators has been normalized using appropriate scaling method keeping in mind diversity among states in their geographical area, size of the economy, and size of population. Since there is no performance benchmark (either nationally or international) available for the indicators, we have used the best performing state as an ideal benchmark and standardized the indicators using the following methods:

In line with the United Nations' Human Development Index (HDI) method, the indicators are transformed into their standardized form, by which the adjusted values of X_{ij} (i.e. AX_{ij}'s) to be used for the analysis become:

$$AX_{ij} = \frac{(X_{ij} - X_i^*)}{(X_i^{**} - X_i^*)} \text{ or } AX_{ij} = \frac{(X_i^{**} - X_i)}{(X_i^{**} - X_i^*)}$$

Where, X_{ij} is the value of jth state with reference to ith indicator. X_i^* and X_i^{**} are the minimum and maximum values for the ith indicator respectively (see Appendix I for indicator-wise application of these two alternate formulae). Now, $AESI_{kj}$ is score of the kth sub-index of AESI for the *j*th State (which constitutes of n number of indicators, *n* varies from 2 to 9) and it is arrived at by averaging the AX_{ij}s over *i* by using the following formula:

$$AESI_{kj} = \frac{1}{n}\sum_{i=1}^{n} AX_{ij}$$

In a similar manner, $AESI_j$, that is, the overall Agri-Environmental Sustainability Index (AESI) score for the *j*th State, is derived by averaging the AX_{ij}s for all *X* over *i* by using the following formula:

$$AESI_j = \frac{1}{N}\sum_{i=1}^{N=40} AX_{ij}\ \forall X$$

The obtained AESIs are relative measure of agri-environmental sustainability (AES) of the States. The States with higher score in AESI (or any sub-index of AESI) having relatively higher AES. The obtained $AESI_j$s (where j = 1 to 17) lead to the ranks of the *j*th State, where States having higher $AESI_j$ get higher rank.

Table 5: Sub-Indices of Agri-Environmental Sustainability Index (AESI)

Description of Sub-Index	Number of Indicators
Sustainable Land Use Index (SLUI)	9
Sustainable Cropping Index (SCI)	5
Sustainable Irrigation index (SII)	7
Sustainable Livestock Index (SLI)	8
Sustainable Agro-Chemical Index (SACI)	2
Sustainable Farm Mechanization Index (SFMI)	3
Population Pressure on Land Index (PPLI)	2
Sustainable Forest Index (SFI)	4
Total	40

Note: Appendix I gives the descriptions of the groups and different indicators used to form each group.

For a few indicators data is available only for different time points, we have taken only those indicators which have at least three observations, and one of these observations falling within the boundary of our three sub-time periods (1990-2000, 2001-2010 and 2011-14). This analysis is based on the State level secondary information available from various published government reports and databases. There may be several other sources of data on Indian agriculture, but those are either not published regularly or not available for all States. In Appendix I we provide indicator-wise list of sources and rationale behind their selection.

4. Results

4.1 Rankings of States during 1990s in Agri-Environmental Environmental Sustainability Index

Table 6 gives the AESI score and ranks of 17 general category states across time periods. It shows that during 1990s, Madhya Pradesh (MP), Rajasthan, Odisha, Karnataka, Goa and Maharashtra are the six better performing States. On the other hand, Punjab, West Bengal, Haryana, Kerala, Tamil Nadu and Uttar Pradesh are the six worst performing States. MP and Rajasthan have the highest AESI ranks, as both the States have done well in almost all sub-indices of AESI, except in Sustainable Farm Mechanization Index (SFMI) and Sustainable Land Use Index (SLUI) by MP and Sustainable Forest Index (SFI) and Sustainable Irrigation Index (SII) by Rajasthan. Punjab and Haryana are the laggards in all sub-indices of AESI. From Table 6 it is evident that different States have different strengths and weaknesses in managing various aspects of AESI. For instance, during 1990s Tamil Nadu has performed well in Sustainable Land Use Index (SLUI), whereas West Bengal has done well in SFMI. Therefore, a comprehensive assessment of AES better reflects the reality than individual indicator based assessment.

4.2 Rankings of States during 2000s in Agri-Environmental Environmental Sustainability Index

Except Andhra Pradesh, Goa, Kerala, Punjab, West Bengal and Odisha, performance of all other states deteriorated during 2000s, as compared to 1990s. Performance deterioration is the most prominent for Gujarat, Bihar, Tamil Nadu and Uttar Pradesh. During 2000s, Goa, Odisha, Rajasthan, Jharkhand, Madhya Pradesh and Chhattisgarh are the six better performing States. Punjab, Haryana, West Bengal, Tamil Nadu, Uttar Pradesh and Gujarat are worst performing states. Punjab and Haryana continue to be worst performers. However, performance Gujarat and Madhya Pradesh have been deteriorated during 2000s. Except in Sustainable Livestock Index (SLI), performance of Gujarat has deteriorated in all other sub-indices of AESI during 2000s. For Madhya Pradesh, considerable fall in performance observed in Sustainable Land Use Index (SLUI) and Sustainable Irrigation index (SII). Performance of Goa has improved considerably during 2000s as compared to 1990s.

4.3 Rankings of States during 2010s in Agri-Environmental Environmental Sustainability Index

Except Gujarat, Punjab, Tamil Nadu and West Bengal, all other states recorded lower AESI score during 2010s as compared to 2000s. Goa, Jharkhand, Odisha, Rajasthan, Chhattisgarh and Madhya Pradesh are the six better performing states during 2010s. Haryana, Punjab, Bihar, West Bengal, Uttar Pradesh and Tamil Nadu are the six worst performing states during the period. Performance of Bihar, Andhra Pradesh and Kerala deteriorated considerably during 2010s. Except in Sustainable Cropping Index (SCI) and Sustainable Farm Mechanization Index (SFMI), performance of Bihar deteriorated during 2010s in all other sub-indices of AESI. Performance of Gujarat improved marginally during 2010s. The analysis supports temporal variations in AES. Regular assessment of environmental sustainability of Indian agriculture is required to capture the dynamic aspects of AES.

4.4 Sensitivity Analysis of Sustainable Agri-Environmental Index Score

To understand sensitivity of the constructed AESI Scores with respect to agricultural intensity, we have tested the relationship between 'state-wise average productivity of foodgrains (in Kg. per hectare)' – as an alternative measure of agricultural intensity – and AESI Score.[5] Figure 2 shows that there is an inverse relationship between AESI Score and average productivity of foodgrains across all time periods of the study. This implies that states are achveing higher productivity of foodgrains at the cost of agri-enviornmental sustainability.

[5] Data on Average Share of Agriculture on GDP (%) is taken from EPWRF India Time Series Database.

Table 6: State-wise Scores and Ranks in Agri-Environmental Sustainability Index (AESI) and Sub-Indices of AESI

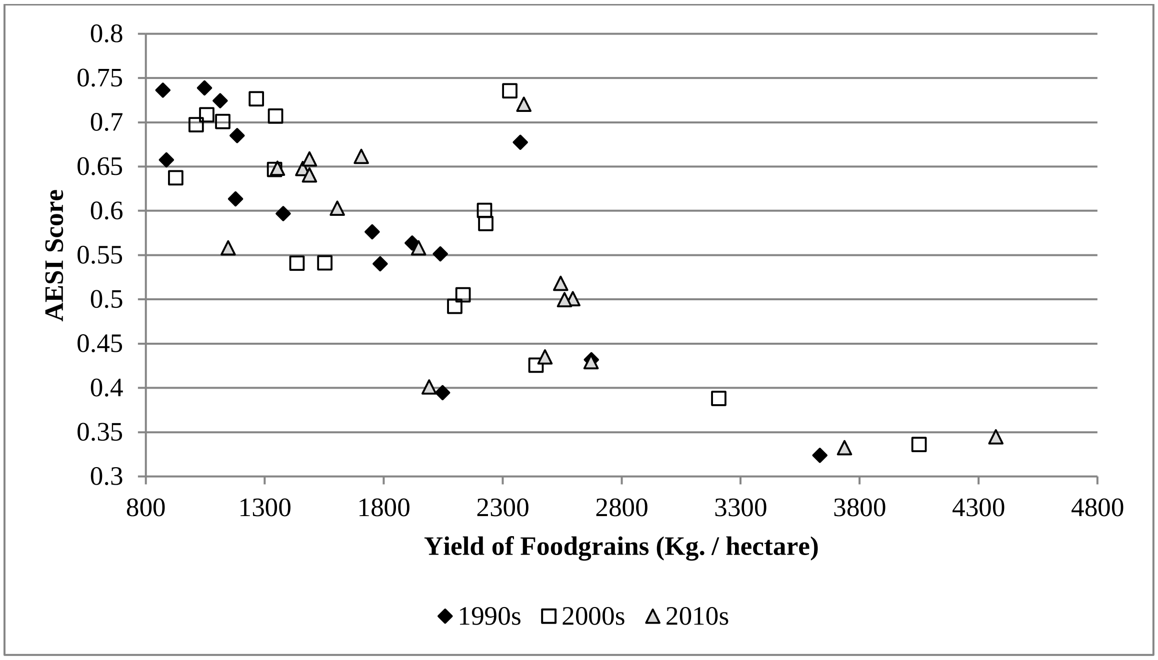
State	Sustainable Land Use Index (SLUI)			Sustainable Croping Index (SCI)			Sustainable Irrigation Index (SII)			Sustainable Livestock Index (SLI)			Sustainable Agro-Chemical Index (SACI)			Sustainable Farm Mechanisation Index (SFMI)			Population Pressure on Land Index (PPLI)			Sustainable Forest Index (SFI)			**Sustainable Agri-Environmental Index (SAEI)**		
	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s
Andhra Pradesh	0.72	0.68	0.55	0.44	0.47	0.33	0.64	0.59	0.56	0.66	0.59	0.40	0.21	0.44	0.20	0.75	0.58	0.56	0.79	0.80	0.84	0.40	0.54	0.57	0.58	0.59	0.50
Bihar	0.70	0.53	0.43	0.47	0.50	0.51	0.61	0.49	0.30	0.50	0.64	0.31	0.79	0.67	0.60	0.93	0.88	0.88	0.41	0.33	0.01	0.35	0.30	0.18	0.60	0.54	0.40
Chhattishgarh		0.61	0.60		0.57	0.54		0.72	0.68		0.77	0.51		0.75	0.77		0.88	0.79		0.92	0.93		0.34	0.37		0.70	0.65
Goa	0.50	0.63	0.59	0.52	0.55	0.53	0.62	0.69	0.79	0.70	0.89	0.69	0.95	1.00	0.99	0.98	0.93	0.90	0.67	0.65	0.71	0.48	0.55	0.57	0.68	0.74	0.72
Gujarat	0.63	0.54	0.49	0.35	0.29	0.48	0.63	0.50	0.48	0.79	0.82	0.55	0.60	0.60	0.67	0.68	0.51	0.65	0.85	0.83	0.85	0.39	0.23	0.31	0.61	0.54	0.56
Haryana	0.36	0.26	0.23	0.37	0.47	0.40	0.43	0.41	0.33	0.48	0.62	0.32	0.18	0.11	0.15	0.71	0.38	0.34	0.68	0.63	0.63	0.24	0.23	0.26	0.43	0.39	0.33
Jharkhand		0.80	0.70		0.56	0.66		0.68	0.73		0.69	0.45		0.91	0.74		0.97	0.92		0.69	0.69		0.36	0.40		0.71	0.66
Karnataka	0.61	0.55	0.59	0.63	0.76	0.65	0.77	0.67	0.68	0.74	0.72	0.55	0.68	0.67	0.64	0.81	0.62	0.46	0.83	0.83	0.85	0.43	0.37	0.41	0.69	0.65	0.60
Kerala	0.54	0.62	0.52	0.53	0.55	0.54	0.68	0.67	0.56	0.59	0.75	0.51	0.70	0.77	0.61	0.92	0.82	0.80	0.02	0.07	0.19	0.35	0.55	0.41	0.54	0.60	0.52
Madhya Pradesh	0.60	0.47	0.38	0.64	0.68	0.66	0.69	0.56	0.53	0.88	0.80	0.61	0.79	0.94	0.89	0.68	0.72	0.71	0.93	0.94	0.92	0.71	0.48	0.44	0.74	0.70	0.64
Maharashtra	0.64	0.53	0.48	0.49	0.56	0.50	0.75	0.68	0.65	0.75	0.80	0.59	0.77	0.75	0.53	0.60	0.65	0.54	0.80	0.79	0.80	0.47	0.34	0.37	0.66	0.64	0.56
Odhisha	0.69	0.75	0.74	0.53	0.52	0.46	0.71	0.59	0.57	0.68	0.75	0.54	0.93	0.92	0.78	1.00	0.98	0.96	0.83	0.82	0.82	0.44	0.49	0.38	0.72	0.73	0.66
Punjab	0.26	0.29	0.18	0.33	0.35	0.41	0.30	0.35	0.31	0.65	0.58	0.61	0.00	0.00	0.00	0.17	0.34	0.32	0.64	0.63	0.66	0.23	0.15	0.27	0.32	0.34	0.34
Rajasthan	0.70	0.50	0.57	0.71	0.80	0.74	0.63	0.65	0.47	0.75	0.80	0.56	0.93	0.91	0.90	0.84	0.74	0.67	1.00	0.98	0.99	0.32	0.29	0.29	0.74	0.71	0.65
Tamil Nadu	0.72	0.83	0.70	0.49	0.56	0.54	0.63	0.63	0.55	0.62	0.42	0.51	0.37	0.34	0.40	0.64	0.32	0.37	0.52	0.55	0.57	0.40	0.28	0.37	0.55	0.49	0.50
Uttar Pradesh	0.54	0.39	0.36	0.43	0.47	0.46	0.47	0.44	0.40	0.75	0.75	0.40	0.58	0.49	0.45	0.85	0.78	0.77	0.49	0.45	0.36	0.39	0.26	0.28	0.56	0.51	0.43
West Bengal	0.47	0.41	0.26	0.40	0.46	0.48	0.38	0.39	0.37	0.16	0.36	0.34	0.49	0.48	0.45	0.99	0.96	0.95	0.02	0.00	0.03	0.26	0.35	0.55	0.39	0.43	0.43

State	Sustainable Land Use Index (SLUI)			Sustainable Croping Index (SCI)			Sustainable Irrigation index (SII)			Sustainable Livestock Index (SLI)			Sustainable Agro-Chemical Index (SACI)			Sustainable Farm Mechanisation Index (SFMI)			Population Pressure on Land Index (PPLI)			Sustainable Forest Index (SFI)			**Sustainable Agri-Environmental Index**		
	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s
Andhra Pradesh	1	4	8	10	13	17	6	9	7	9	14	14	13	14	15	9	13	12	7	7	6	6	3	1	9	10	11
Bihar	4	11	12	9	11	9	11	13	17	13	12	17	4	10	10	4	6	5	13	15	17	10	11	17	8	11	15
Chhattishgarh		7	4		4	6		1	4		6	11		7	5		5	7		3	2		10	9		6	5
Goa	12	5	6	6	8	8	10	2	1	7	1	1	1	1	1	3	4	4	9	10	9	2	2	2	5	1	1
Gujarat	7	9	10	14	17	12	7	12	11	2	2	6	9	11	7	12	14	11	3	4	4	9	15	12	7	12	8
Haryana	14	17	16	13	14	16	13	15	15	14	13	16	14	16	16	10	15	16	8	11	12	14	16	16	13	16	17
Jharkhand		2	3		6	2		4	2		11	12		5	6		2	3		9	10		7	7		4	2
Karnataka	8	8	5	3	2	4	1	6	3	6	10	7	8	9	8	8	12	14	4	5	5	5	6	6	4	7	7
Kerala	10	6	9	4	9	5	5	5	8	12	7	9	7	6	9	5	7	6	15	16	15	11	1	5	12	9	10
Madhya Pradesh	9	13	13	2	3	3	4	11	10	1	3	3	5	2	3	11	10	9	2	2	3	1	5	4	1	5	6
Maharashtra	6	10	11	8	7	10	2	3	5	5	4	4	6	8	11	14	11	13	6	8	8	3	9	11	6	8	9
Odhisha	5	3	1	5	10	13	3	10	6	8	9	8	2	3	4	1	1	1	5	6	7	4	4	8	3	2	3
Punjab	15	16	17	15	16	15	15	17	16	10	15	2	15	17	17	15	16	17	10	12	11	15	17	15	15	17	16
Rajasthan	3	12	7	1	1	1	9	7	12	4	5	5	3	4	2	7	9	10	1	1	1	12	12	13	2	3	4
Tamil Nadu	2	1	2	7	5	7	8	8	9	11	16	10	12	15	14	13	17	15	11	13	13	7	13	10	11	14	12
Uttar Pradesh	11	15	14	11	12	14	12	14	13	3	8	13	10	12	13	6	8	8	12	14	14	8	14	14	10	13	13
West Bengal	13	14	15	12	15	11	14	16	14	15	17	15	11	13	12	2	3	2	14	17	16	13	8	3	14	15	14

Note: Upper Panel shows the AESI and Sub-index-wise scores of States and lower panel shows the corresponding ranks

Source: Computed

Figure 2: Relationship between Agri-Environmental Sustainability Index (SAEI) Score and Agricultural Intensity

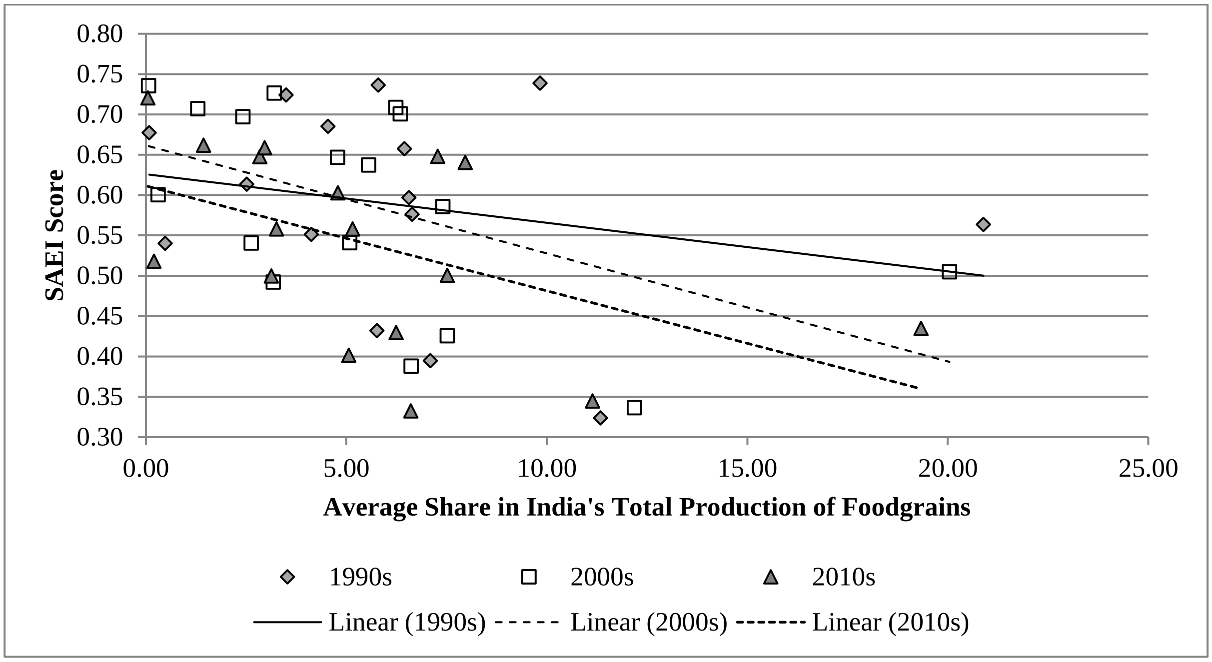


Source: Computed

Agriculture is not just an economic activity for developing countries like India; it is source of food security and livelihoods. For populated country like India, self-sufficiency in food production is important for macroeconomic stability and overall economic development. To check whether there is any relationship between food security and AES, we have plotted AESI Scores over 'state-wise average share in India's total foodgrains production' in Figure 3.[6] We found that there is an inverse relationship between the two for all the periods. It implies that States having higher share in total foodgrains production also have lower AESI score. In other words, States which produce maximum foods are deteriorating their agri-environment. Decoupling food production from AES is a challenge not only for developing countries like India but also for developed countries (Yang et al. 2017, González de Molina et al. 2017). Therefore, better targeting of agri-environmental policies for states where maximum foodgrains are produced could help to achieve AES in India.

[6] For sources of data, please see Appendix II.

Figure 3: Relationship between ASEI Score and Average in India's Total Foodgrains Production



Source: Computed

5. Impacts of Agriculture on Environment

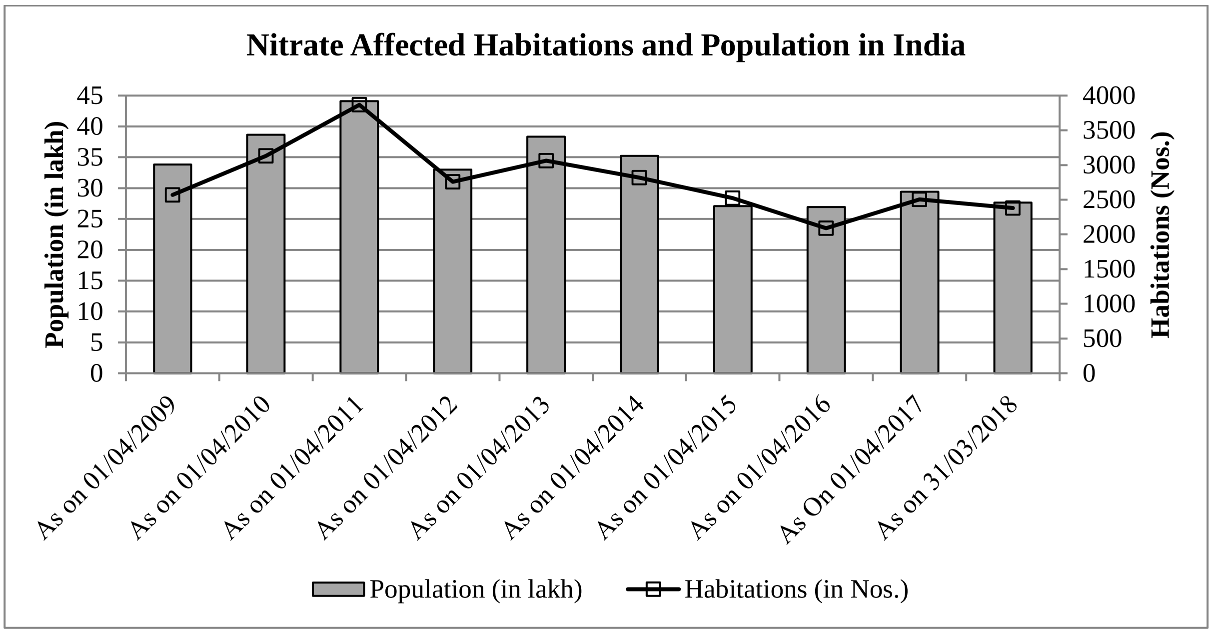
The impacts of agriculture on environment and natural resources are multi-dimensional. To validate whether the constructed AESI and sub-indices reflect reality with reference to existing evidences of agr-environmental impacts, we have considered groundwater depletion and degradation, land degradation and depletion of soil nutrients.

5.1 Agricultural Nonpoint Source Water Pollution: Groundwater Nitrate Pollution

Runoffs from agricultural land laced with nutrients (nitrogen and phosphorous) causes impairment of surface water bodies. In several parts of India, growing access to irrigation facilities along with unbalanced and overuse of nitrogenous fertilizers, unlined and open storage of livestock wastes, and insanitary disposal of human wastes have led to high concentration of nitrate in groundwater (Mukherjee 2008). Nonpoint source (NPS) pollution from agriculture and animal husbandry is one of the major causes of water pollution not only for developing countries but also for developed countries. There is limited information on the level of pesticide contamination of water sources. However, there is substantial secondary information on the level of nitrate contamination of groundwater. Groundwater serves as decentralized source of drinking water for many people in India. Consumption of nitrate contaminated drinking water poses various short and long term health hazards to various age groups (WHO 2004). Nitrate (NO_3) concentration in water used for drinking should be less than 50 milligram per litre (mg/l) (WHO 2004). In India, according to the Bureau of Indian Standard (BIS 1991), the maximum acceptable limit of nitrate in drinking water is 45 mg/l (which is equivalent to 10 mg/l of nitrate-nitrogen, NO_3-N). However, the maximum permissible limit of nitrate is set at 100 mg/l, provided there are no alternative source(s) of drinking water (BIS 1991).

Figure 4 shows that a large number of populations are affected by drinking water nitrate pollution (having nitrate above 45 mg/l) in India. High dependence on nitrogenous fertilizers and cultivation of water intensive crops (sugarcane, paddy, wheat etc.) has led to NPS groundwater pollution in intensively cultivated areas of India.

Figure 4: Nitrate Affected Habitations and Population in India



Data Source:
https://indiawater.gov.in/IMISReports/Reports/Physical/rpt_RWS_NoOfQualityAffHabitations_S.aspx?Rep=0&RP=Y&APP=IMIS (last accessed on 5 June 2018).

Table 6 shows that states having lower scores in Sustainable Livestock Index (SLI) and Sustainable Agro-Chemical Index (SACI) have higher percentage of observation wells with nitrate concentration above 45 mg/l. This shows that managing livestock wastes and fertilizer application could help in managing groundwater quality.

Table 6: State-wise Groundwater Nitrate Pollution in Shallow Aquifers in India*

State	No. of Water Quality Monitoring Stations (as on 31 March 2015)#	No. of Observations having Nitrate Concentration > 45 mg/l		No. of Observations having Nitrate Concentration > 100 mg/l		Maximum Nitrate Concertation Reported (mg/l)
Andhra Pradesh$	1132	325	(28.7)	159	[48.9]	1331
Bihar	643	45	(7.0)	11	[24.4]	327.5
Chhattisgarh	489	37	(7.6)	7	[18.9]	176.2
Goa	102	nil	n.a.	nil	n.a.	n.a.
Gujarat	810	178	(22.0)	63	[35.4]	400
Haryana	529	58	(11.0)	35	[60.3]	1876
Jharkhand	407	44	(10.8)	13	[29.5]	316
Karnataka	1438	222	(15.4)	45	[20.3]	398
Kerala	364	33	(9.1)	3	[9.1]	206
Madhya Pradesh	1137	229	(20.1)	79	[34.5]	348
Maharashtra	1515	225	(14.9)	1	[0.4]	171
Odisha	1659	116	(7.0)	43	[37.1]	707
Punjab	351	55	(15.7)	28	[50.9]	700
Rajasthan	613	225	(36.7)	99	[44.0]	4405
Tamil Nadu	457	83	(18.2)	31	[37.3]	511
Uttar Pradesh	892	55	(6.2)	22	[40.0]	930
West Bengal	666	nil	n.a.	nil	n.a.	n.a.

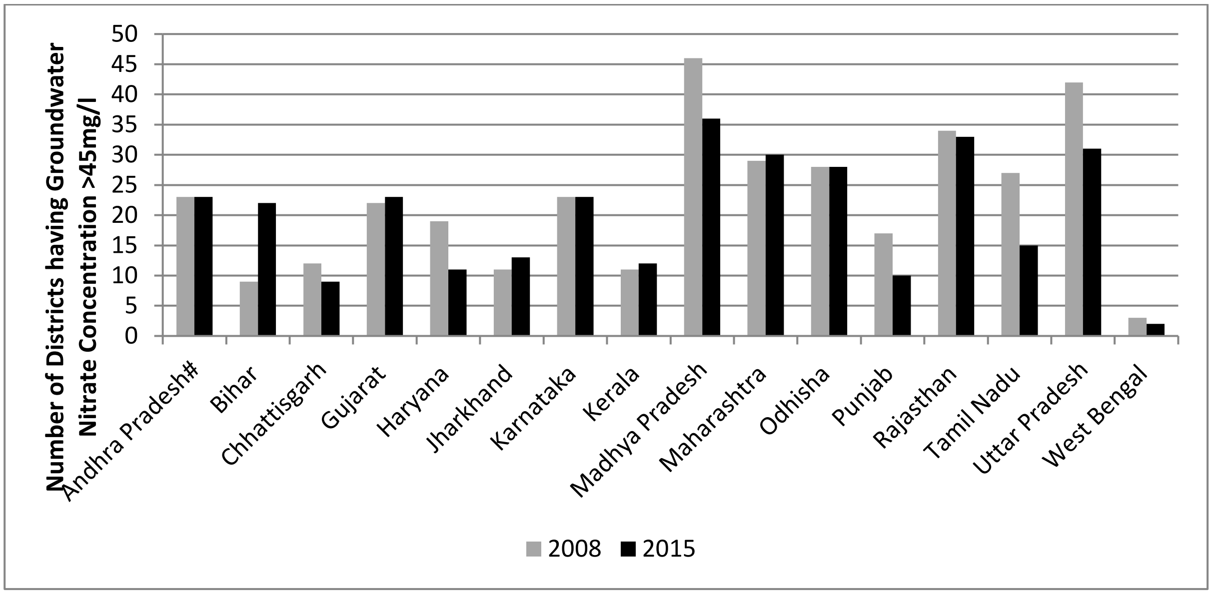
Note: # - It cannot be confirmed from the CGWB (2018) whether all monitoring stations are operational and all samples lifted are adequate for water quality analysis. $-including Telangana. *-The dataset provides nitrate concentration for only those monitoring stations which exceed 45 mg/l.

Figures in the parenthesis show the percentage share in total number monitoring stations located in the state. Figures in the bracket show the percentage share in number of observations having nitrate concentration > 45mg/l.

Data Source: CGWB (2018)

Figure 5 shows that except Bihar, Gujarat, Kerala and Maharashtra, for other states districts affected by groundwater nitrate pollution either declined or remain unchanged during 2008 to 2015. The deteriorating groundwater quality for some states may be attributed to rising stress (depletion) on groundwater and/or increasing pollution load reaching to groundwater. This also shows that water quality varies over time and therefore regular monitoring of groundwater quality is important for effective management of water resources.

Figure 5: State-wise Comparative Change in Number of Districts having Groundwater Nitrate Concentration > 45mg/l



Note: #-Undivided
Data Source: CGWB (2018, Page No. 23)

5.2 Depletion of Groundwater

Central Ground Water Board (CGWB) monitors groundwater levels across States/ UTs in India through a network of monitoring wells. As on March 2017 there are 21,555 monitoring wells (15,482 dug wells and 6,073 piezometers) located in 18 general category states in India (CGWB undated). Majority of Indian States are receiving southwest monsoon and as compared to pre-monsoon groundwater recharge during monsoon is visible by the difference in water level fall (Table 7). However, it is also to be noted that monsoon cannot fully replenish fall in groundwater table as a result fall in water level persists with reference to decadal (2006-15) average. For states receiving retreating (northeast) monsoon, precipitation received during November 2016 to January 2017 was not much effective to replenish groundwater level. Falling water level is observed for more than half of the monitoring stations located across all states. Growing emphasis on groundwater based irrigation and providing free / subsidized electricity in some states are the major causes of groundwater depletion in India.

Table 7: Decadal Changes in Groundwater Level in General Category States

Fall in Water Level	Pre-monsoon 2016 with decadal mean of Pre-monsoon (2006-2015)		August 2016 (Post-monsoon) with decadal mean of August (2006-2015)		November 2016 (Pre-monsoon) with decadal mean of November (2015-2016)*		January 2017 (Post-monsoon) with decadal mean of January (2007-2016)*	
0-2 meter	6,408	(46.2)	5,159	(38.1)	6,043	(42.7)	6,397	(42.9)
2-4 meter	1,727	(12.5)	1,255	(9.3)	1,409	(10.0)	1,554	(10.4)
> 4 meter	1,025	(7.4)	787	(5.8)	908	(6.4)	1,049	(7.0)
Total	9,160	(66.1)	7,201	(53.2)	8,360	(59.1)	9,000	(60.3)
Total Sample Wells Tested	13,864	(100)	13,539	(100)	14,152	(100)	14,923	(100)

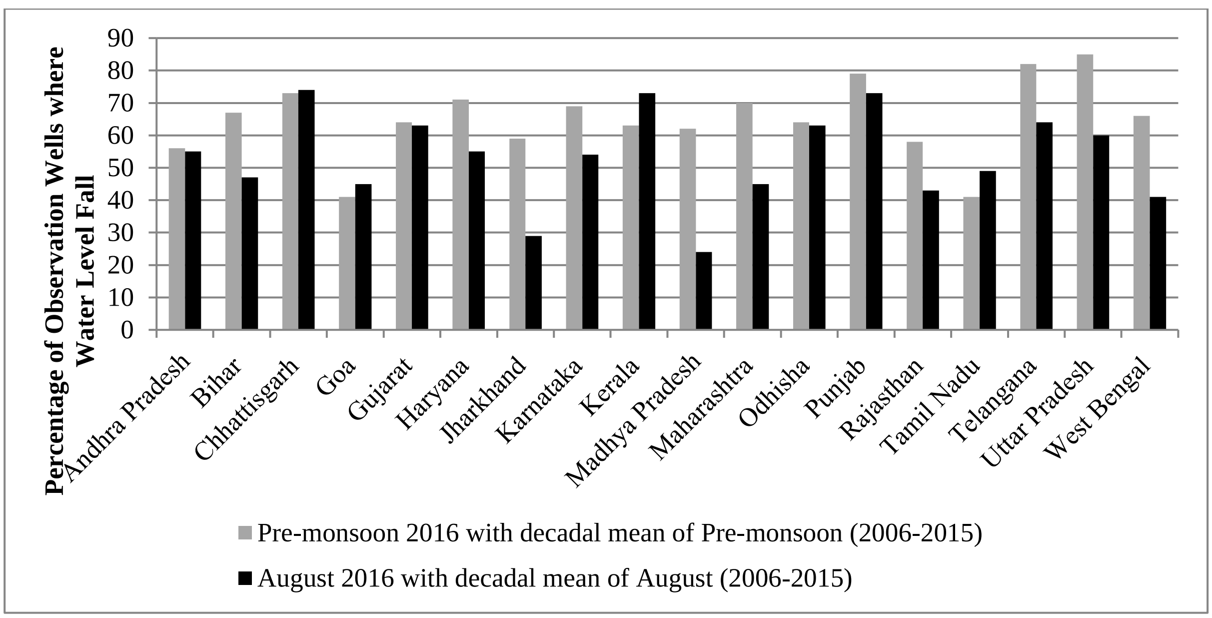
Note: Figures in the parenthesis show the percentage share in Total Sample Wells Tested

*-For States receiving retreating (northeast) monsoon, November is the pre-monsoon and January is the post monsoon.

Source: CGWB (undated)

Except Chhattisgarh, Goa, Kerala and Tamil Nadu, water level improves in August 2016 (post-monsoon) as compared to pre-monsoon 2016. Replenishment of groundwater during monsoon is visible from Figure 6 for majority of Indian states. Tamil Nadu receives retreating monsoon during the month of December, as a result Figure 6 does not show any improvement (replenishment) of groundwater level for Tamil Nadu.

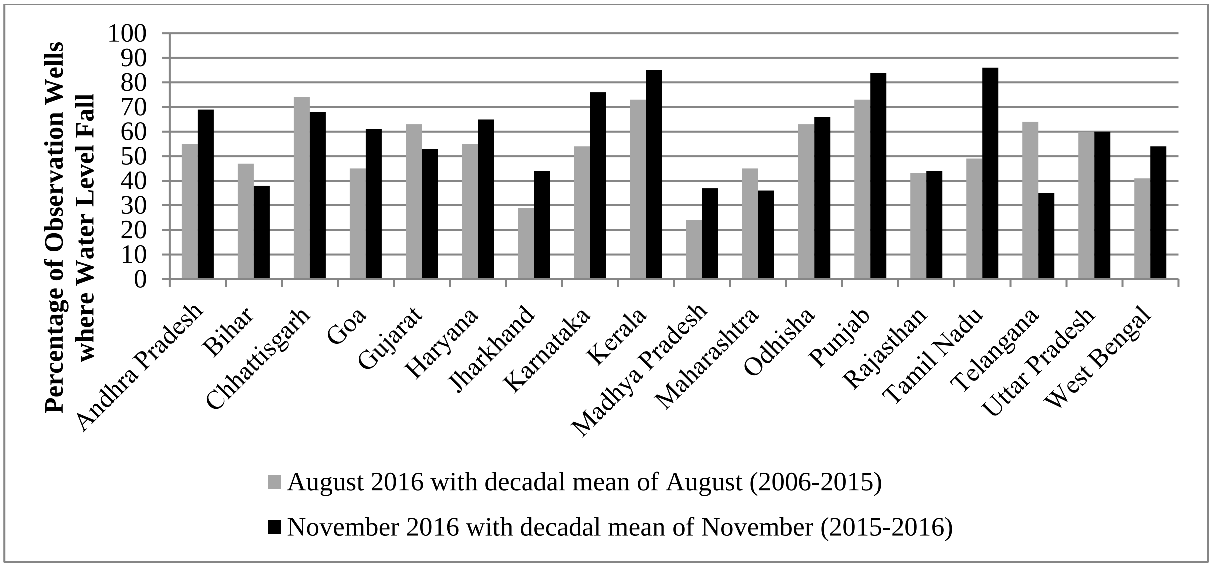
Figure 6: State-wise Groundwater Replenishment during South-West Monsoon of 2016



Source: CGWB (undated)

Figure 7 shows that within three months (August 2016 to November 2016) of monsoonal replenishment of groundwater, for majority of Indian states groundwater level falls. Falling groundwater level during August to November is largely attributable to withdrawal of groundwater for Kharif (July –October) crops.

Figure 7: State-wise Groundwater Withdrawal during Post- South-West Monsoon and Pre-North-East Monsoon of 2016

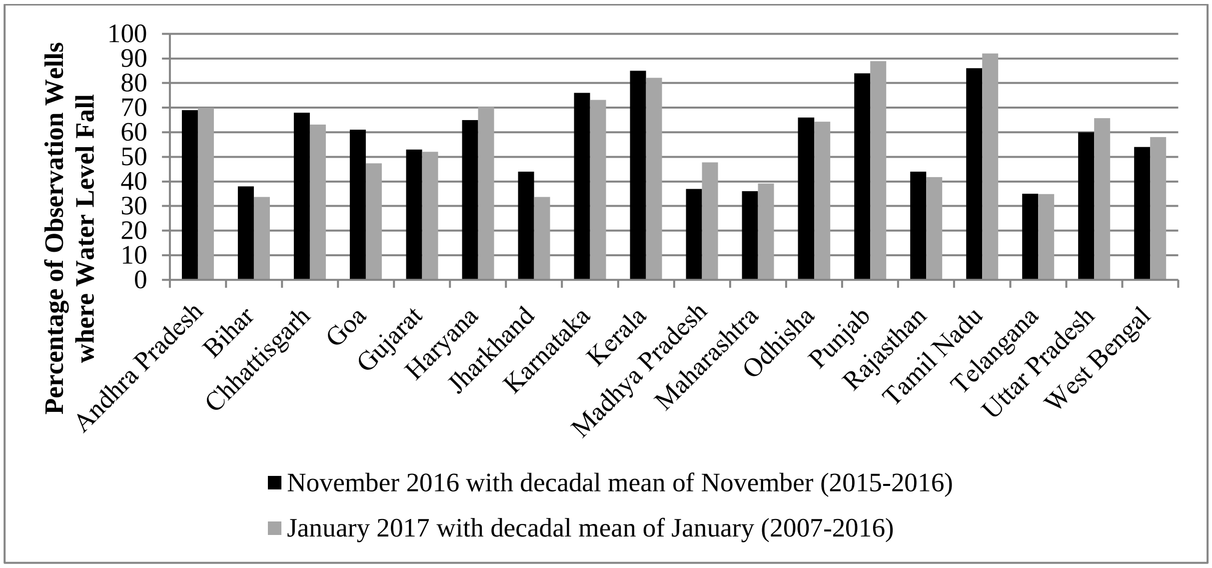


Source: CGWB (undated)

During November 2016 to January 2017, there is hardly any change in water level. Though Tamil Nadu and Kerala receive retreating monsoon during December, there is hardly any improvement in water level in the post-monsoon (January 2017). This shows weak replenishment of groundwater in Kerala and Tamil Nadu. Showing of Rabi (October to March) crops result in withdrawal of water which is reflected in marginal fall in water table.

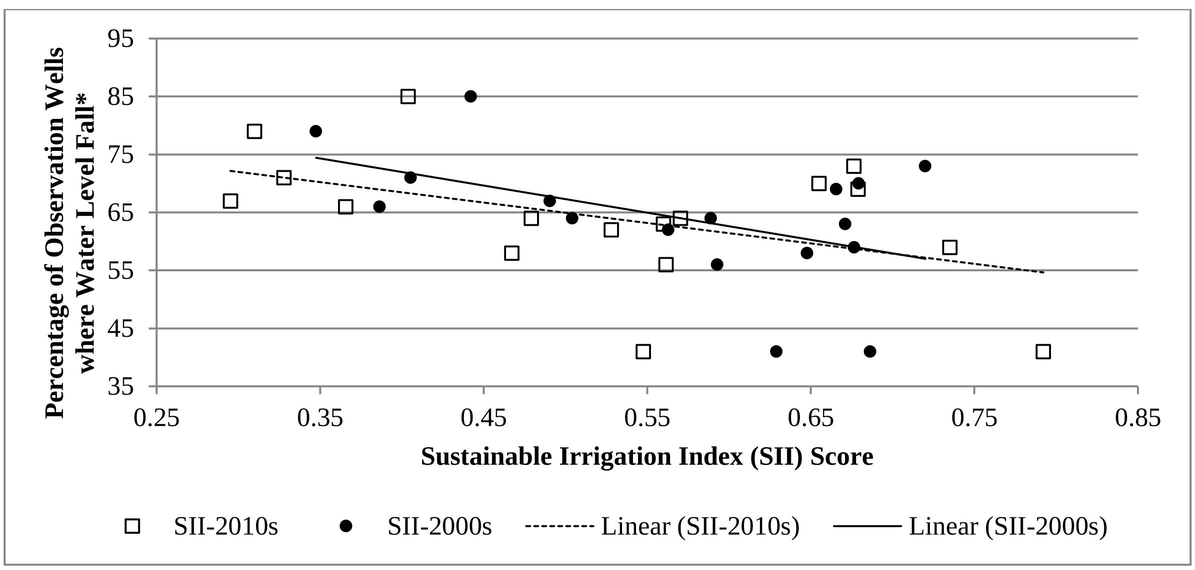
Depletion of groundwater is largely depends on agricultural withdrawal of water. Sustainable irrigation practices could help in sustainable management of groundwater resources. Figure 9 shows that states having higher score in Sustainable Irrigation Index (SSI) are facing lower fall in groundwater level. Similar relationships are also found for other data tables presented above. This not only validates our methodology and selection of indicators for construction of SII but also supports causal relationship between irrigation practices and groundwater management.

Figure 8: State-wise Groundwater Replenishment during North-East Monsoon of 2016-17



Source: CGWB (undated)

Figure 9: Relationship between Sustainable Irrigation Index (SSI) Score and Fall in Groundwater Level*



Note: *-Pre-monsoon 2016 with decadal mean of Pre-monsoon (2006-2015)
Source: Computed

5.3 Land Degradation

Land degradation/ desertification are major environmental challenges for India in achieving AES. Bhattacharyya et al (2015) has identified the following causes of land degradation and majority of them are related to AES:

- *Overgrazing*, Deforestation and Careless Forest Management
- Urban Growth, Industrialization and Mining
- Natural and Social Sources of land Degradation
- Land Shortage, Land Fragmentation and Poor Economy
- Population Increase
- *Low and Imbalanced Fertilization*
- *Excessive Tillage and Use of Heavy Machinery*
- *Crop Residue Burning and Inadequate Organic Matter Inputs*
- *Poor Irrigation and Water Management*
- *Poor Crop Rotations*
- *Pesticide Overuse and Soil Pollution*

According to Space Application Centre (2016), more than 30 percent of total area is under land degradation/ desertification. The major causes of land degradation are water erosion, vegetation degradation and wind erosion. As compared to 2003-05, percentage of degraded land in total area has gone up marginally.

Table 8: Status of Desertification / Land Degradation in India (area in million ha)

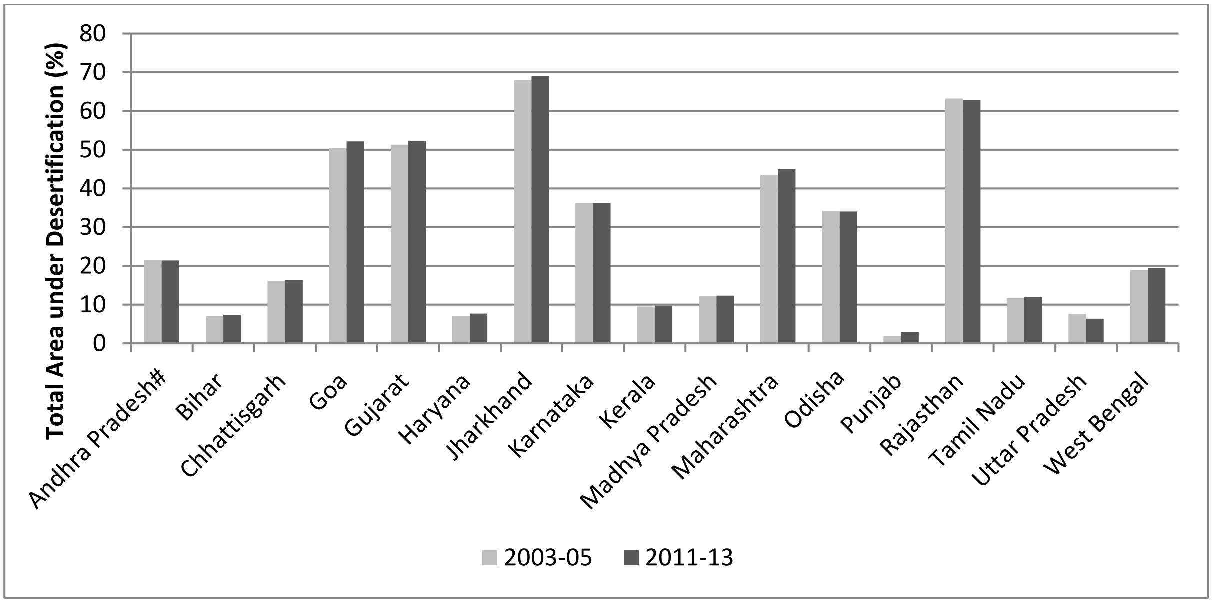
Types of Land Degradation	2003-05		2011-13	
Vegetation Degradation	21.9	(26.9)	22.1	(27.0)
Water Erosion	35.0	(43.0)	35.4	(43.2)
Wind Erosion	16.7	(20.5)	16.6	(20.2)
Salinity	4.0	(4.9)	3.7	(4.5)
Water Logging	0.3	(0.4)	0.4	(0.5)
Manmade	0.4	(0.5)	0.4	(0.5)
Barren/Rocky	1.7	(2.0)	1.7	(.0)
Settlement	1.3	(1.6)	1.7	(2.0)
Total Area under Desertification	**81.3**	**(100)**	**81.8**	**(100)**
Total Area under Desertification (%)	30.3		30.5	
No Apparent Degradation	182.5		181.8	
Total Area	**268.3**		**268.3**	

Source: Space Application Centre (2016)

Note: Figure in the parenthesis shows the percentage share in Total Land Area under Desertification.

Among states, maximum land degradation is reported in Jharkhand, Rajasthan, Goa, Gujarat, Maharashtra, Karnataka and Odisha (Figure 10). Mining in Jharkhand, Goa and Odisha could be reason behind large scale land degradation. Sustainable land use management could help to reduce degradation of land.

Figure 10: State-wise Status of Desertification / Land Degradation



Source: Space Application Centre (2016)

5.4 Depletion of Soil of Nutrients

Under the National Mission for Sustainable Agriculture (NMSA), soil health management (SHM) is initiated to promote "Integrated Nutrient Management (INM) through judicious use of chemical fertilizers including secondary and micro nutrients in conjunction with organic manures and bio-fertilizers for improving soil health and its productivity; strengthening of soil and fertilizer testing facilities to provide soil test based recommendations to farmers for improving soil fertility; ensuring quality control requirements of fertilizers, bio-fertilizers and organic fertilizers under Fertilizer Control Order, 1985".[7] Under this programme, soil testing is an integrated part, and in Cycle I (2015-16 to 2016-17) 14.97 million soil samples are tested for general category states till 23 January 2018. Out of these samples, 2.82 million (18.8%) samples have Boron (B) deficiency, 0.63 million (4.2%) samples have Copper (Cu) deficiency, 4.37 million (29.2%) samples have Iron (Fe) deficiency, 1.75 million (11.7%) samples have Manganese (Mn) deficiency, 3.86 million (25.8%) samples have Sulphur (S) deficiency, 4.63 million (30.9%) samples have Zinc (Zn) deficiency. In macronutrients, 86.6 percent samples have Nitrogen (N) deficiency (very low and low), 21.7 percent samples have Phosphorous (P) deficiency, 15.3 percent samples have

[7] https://soilhealth.dac.gov.in/Content/blue/soil/about.html (last accessed on 19 July 2019).

Potassium (K) deficiency, and 56.4 percent samples have Organic Carbon (OC) deficiency (Table 9). This shows that large scale depletion of soil nutrients (both micro and macro) in India. Though farmers manages deficiencies in macronutrients by applying both chemical fertilizers and farmyard manure, compensating for micronutrient deficiencies is a major challenge for farmers. In the absence of sustainable soil management programme at the firm level, meeting India's long-run agricultural productivity would be a challenge.

Table 9: Nutrients Deficiency of Indian Soil

Macronutrient	Very Low	Low	Medium	High	Very High	Total Samples
Nitrogen (N)						
Reference Guideline (N Kg/ha)	<140	140-280	280-560	560-700	>700	
No. of Samples (in lakh)	29.4	54.9	10.7	1.0	1.3	97.4
% of Total Samples	30.2	56.4	11.0	1.0	1.3	
Phosphorous (P)						
Reference Guideline (P Kg/ha)	<15	15-30	30-65	65-80	>80	
No. of Samples (in lakh)	21.3	11.2	65.0	21.6	30.4	149.5
% of Total Samples	14.3	7.5	43.5	14.5	20.3	
Potassium (K)						
Reference Guideline (K Kg/ha)	<120	120-180	180-300	300-360	>360	
No. of Samples (in lakh)	14.8	7.9	73.9	42.6	9.6	148.9
% of Total Samples	10.0	5.3	49.6	28.6	6.5	
Organic Carbon (OC)						
Reference Guideline (%)	<0.20	0.20-0.40	0.40-0.80	0.80-1.00	>1.00	
No. of Samples (in lakh)	9.6	73.8	25.8	27.3	11.5	148.0
% of Total Samples	6.5	49.9	17.4	18.4	7.8	

Source: Data accessed from https://soilhealth.dac.gov.in/

There are many aspects of AES which impact soil health. To assess the impact of sub-indices of AESI on state-wise soil nutrient deficiency we have conducted correlation between individual score of sub-indices and percentage of soil samples having macronutrients deficiency (very low and low). In Table 10 we report the results for only those correlations where coefficient is higher than 30 percent. There are negative correlations across sub-indices and macronutrient deficiencies. This supports that constructed sub-indices and reflect the state of soil health across Indian states. We do not find any significant correlation of macronutrients deficiency and Population Pressure on Land Index (PPLI).

Table 10: Correlation among Sub-indices of AESI and State level Micronutrient Deficiency for 2010s

Sub-Indices of AESI	Percentage of Soil Samples having Very Low and Low			
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Organic Carbon (OC)
Sustainable Land Use Index (SLUI)			**-0.33**	
Sustainable Cropping Index (SCI)		**-0.42**	**-0.42**	
Sustainable Irrigation Index (SII)			**-0.33**	**-0.40**
Sustainable Livestock Index (SLI)	**-0.54**			
Sustainable Agro-Chemical Index (SACI)		**-0.31**	**-0.65**	**-0.43**
Sustainable Farm Mechanization Index (SFMI)			**-0.36**	**-0.57**
Sustainable Forest Index (SFI)				**-0.59**
Sustainable Agri-Environmental Index (SAEI)			**-0.48**	**-0.37**

Source: Computed

5.5 Emission of Greenhouse Gases from Agriculture

Agriculture contributes 67 percent of total methane (CH_4) emission and 61 percent of total nitrous oxide (N_2O) of India in 2007 (INCAA 2010). Contribution of agriculture in total CO_2 equivalent (CO_{2eq}) emission of India is 19.4 percent (Table 11). In total emission of CO_{2eq} of agriculture, 63.4 percent is contributed by enteric fermentation of livestock, 21 percent by rice cultivation. Emission of methane from rice cultivation is largely dependent on access to irrigation and method of irrigation. Cultivation of rice under continuous flood irrigation method and /or in flood prone areas contributes maximum methane emission. In a recent study by Some at al. (2019) concludes that total non-CO_2 emission from cropland based agricultural activities has increased from 104.69 $MtCO_{2eq}$ in 1980-81 to 156.1 $MtCO_{2eq}$ in 2014-15, an approximately 49 percent rise. Traditional paddy cultivation practice change in favor of less water using practices led to marginal reduction in non-CO_2 GHGs emission. The rise in non-CO_2 emission from increasing use of N-fertilizer could be clearly attributed to the link between fertilizer pricing policy and disproportionately higher use of N-fertilizer going beyond officially prescribed ratios." State-wise and source-wise inventory of emissions of GHGs is not available at present and therefore it is difficult to include such indicators in the present AESI.

Table 11: Contribution of Agriculture Sector in Green House Gases Emissions ('000 tonne)

Source	Methane (CH_4)	Nitrous Oxide (N_2O)	Carbon Dioxide Equivalent (CO2eq)	
Enteric fermentation	10.10		212.10	(63.4)
Manure management	0.12	0.0001	2.44	(0.7)
Rice cultivation	3.33		69.87	(20.9)
Agriculture Soils		0.14	43.40	(13)
Field burning of agriculture crop residue	0.23	0.01	6.61	(2)
Total - Agriculture	**13.77**	**0.15**	**334.41**	**(100)**
	[67.0]	[61.0]	[19.4]	
Total - India	20.56	0.24	1727.71	

Note: Figures in the parenthesis show the percentage share in total CO2eq emission from agriculture. Figures in the bracket show the percentage share in India's total emission.
Source: INCCA (2010)

6. Conclusions and Policy Suggestions

In the absence of SEEA in India, present paper builds a comprehensive agri-environmental sustainability index (AESI) for 17 major Indian States. Based on literature review and assessment of availability of time series data at State level, a list of 40 agri-environmental indicators (AEIs) are identified to measure agri-environmental sustainability (AES). These indicators are classified into eight groups or sub-indices of AESI. To capture temporal variations of agricultural impacts on environment, the entire period of the study (i.e., 1990-91 to 2013-14) is divided into three sub-periods - 1990s (1990-91 to 1999-2000), 2000s (2000-01 to 2009-10) and 2010s (2010-11 to 2013-14). While 1990s mark the early years of economic liberalization, 2000s mark high economic growth period and 2010s mark the low growth period.

The results show that different States have different strengths and weaknesses in managing various aspects of AESI. Therefore, a comprehensive assessment of AES better reflects the reality than individual indicator based assessment. We find that AESI score (and associated sub-indices score) changes over time and therefore regular assessment of environmental sustainability of Indian agriculture is required to capture the dynamic aspects of AES.

States having lower scores in Sustainable Livestock Index (SLI) and Sustainable Agro-Chemical Index (SACI) have higher percentage of observation wells with nitrate concentration above 45 mg/l. Depletion of groundwater is largely depends on agricultural withdrawal of water. Sustainable irrigation practices could help in sustainable management of groundwater resources. States having higher score in Sustainable Irrigation Index (SSI) are facing lower fall in groundwater level. This not only validates our methodology and selection of indicators for construction of SII but also supports causal relationship between irrigation practices and groundwater management.

There are many aspects of AES which impact soil health. We find that there are negative correlations across AESI sub-indices and macronutrient deficiencies. This supports that constructed sub-indices reflect the state of soil health across Indian states. State-wise and source-wise inventory of emissions of GHGs is not available at present and therefore it is difficult to include such indicators in the present AESI.

There is an inverse relationship between AESI Scores and agricultural intensity (as measured by average productivity of foodgrains). It implies that states are achieving higher productivity of foodgrains at the costs of their agri-environmental sustainability. Growing intensity of agriculture to meet demands for food, fibre and fodder results in stress on environment and natural resources. It is expected that after reaching the turning point (maximum carrying capacity of environment and natural resources), agricultural productivity will fall. Though it cannot be projected in the present study when the turning point will arrive, it would be important to adopt "precautionary principle' and include agri-environmental sustainability as an objective in overall policies / programmes of the government. Decoupling food production from AES is a challenge not only for developing countries like India but also for developed countries. Better targeting of agri-environmental policies for states where maximum foodgrains are produced could help to achieve AES in India.

Integration agricultural policies with environment, water and land use policy would be the first step towards achieving sustainability in Indian agriculture. Agriculture is the predominant user of fresh water in India. Pricing irrigation water is a contentious political issue. In the absence of measuring volumetric discharge of water in each farm land, many states have priced irrigation water based on second best method – based on crop season (Kharif, Rabi, and hot weather), number of irrigations, area under irrigation and choice of crops. However, enforcement of pricing, raising demand and recovery of water charges vary across states. In the absence of proper pricing and recovery of water charge, true cost of water is not reflected as a result water use efficiency in agriculture remains low (Mukherjee and Leflaive 2018). In addition, many states provide free / subsidized electricity to farmers (e.g., Punjab, Haryana), as a result cost of abstraction of water becomes free. High reliance on groundwater based irrigation system and over extraction of groundwater has resulted in fall in groundwater level in many states in India. In a recent study World Resources Institute (WRI) has categorized India as one of the extremely high water stress countries in the world (similar to Middle East countries like Qatar, Israel, and Lebanon). Most of the water stressed states are located in North-West and Southern parts of India.[8] Proper pricing of irrigation

[8] https://www.wri.org/blog/2015/02/3-maps-explain-india-s-growing-water-risks

water and electricity for agricultural uses may help to reduce stress on Indian water resources.

Union government provides subsidy on fertilizers (urea, phosphorous, potash, city compost). 66 percent of the annual subsidy goes to urea (indigenous as well as imported) and the rest on other fertilizers. Farmers do not pay actual price of fertilizers and since the fertilizer subsidy policy favors urea over others, unbalanced and overuse of urea lead to runoff and leaching of nutrients into surface water bodies and groundwater. Application of nitrogen-fertilizers for foodgrain crops accounts for 69 percent of total consumption of N-fertilizers in India, out of which rice and wheat consume about 61 percent (Prasad 2011). Average nitrogen use efficiency varies from 21-33 percent whereas agronomic efficiency value is 4-17 kg grain/kg N in rice-wheat cropping system (Prasad 2011). It implies that two-thirds of applied N-fertilizer is lost in the environment. Improving fertilizer management practices – e.g., crop-specific application of fertilizers after soil testes could increase fertilizer use efficiency. It would be desirable from the government to provide free agricultural extension services and encourage farmers to adopt agricultural best management practices rather than providing environmentally harmful subsidies which are detrimental for agri-environmental sustainability.

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Appendix I

Sustainable Development Goals, Targets and Indicators related to Agri-Environmental Sustainability

SDG Goal	Target	Indicator	Remarks
1. End poverty in all its forms everywhere	1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day	1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural)	Agri-environmental sustainability (AES) is important to achieve agricultural sustainability and sustainable income for people dependent on agriculture and allied activities
	1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their *exposure and vulnerability to climate-related extreme* events and other economic, social and environmental shocks and disasters	1.5.3 Number of countries with national and local disaster risk reduction strategies	Adoption of sustainable agricultural practices could reduce vulnerability to climate related extremes like droughts
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	2.1.1 Prevalence of undernourishment 2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)	AES is important for sustainable food production and achieving food (nutritional) security
	2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	AES is important to reduce agriculture related land degradation and depletion of soil nutrients

	ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality		
	2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed	2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium or long-term conservation facilities	Crop rotations and crop diversifications are traditional practices followed to replenish soil nutrients and conserve biodiversity. Applications of harmful pesticides are threat to various plant and animal species. ASE could help to conserve biodiversity.
	2.A Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries	2.A.1 The agriculture orientation index for government expenditures 2.A.2 Total official flows (official development assistance plus other official flows) to the agriculture sector	Public support on agricultural research and extension services, technology development could help farmers to adopt sustainable agricultural practices. Many developed countries support farmers to adopt conservation agricultural practices.

6. Ensure availability and sustainable management of water and sanitation for all	6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services	Nutrients flows from agricultural activities impair surface water and groundwater resources. Protection of drinking water sources from nonpoint sources of pollution important to achieve sustainable access to safe drinking water.
	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated 6.3.2 Proportion of bodies of water with good ambient water quality	Leaching of nitrate from farmlands and animal waste storage are the major contributors of groundwater nitrate pollution in rural areas in India (Mukherjee 2008). Adoption of agricultural best management practices (BMPs) could reduce pollution load (Mukherjee 2015).
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	Agricultural is the major consumer of freshwater and water use efficiency in Indian agriculture is low. Increasing water use efficiency through alternative irrigation practices could reduce water withdrawals as well as wastage of nutrients
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0-100) 6.5.2 Proportion of transboundary basin area with an operational	Increasing demands from alternative uses of water due to growing population, urbanization and rising industrial activities, make little water available for

		arrangement for water cooperation	agriculture. Rising water conflicts and inter-sectoral water rights are signs that in future agriculture needs to manage with marginal quality water (Mukherjee and Nelliyat 2006).
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time	AES could play an important role in protecting water environment and related eco-system.
	6.B Support and strengthen the participation of local communities in improving water and sanitation management	6.B.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	Participation of stakeholders in water resources management especially in agriculture sector could play an important role. Farmers' behavioral aspects play an important role in adoption of agricultural BMPs.
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries	8.1.1 Annual growth rate of real GDP per capita	Agricultural sustainability is important for developing countries like India to sustain economic growth and equitable distribution of income
	8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-	8.2.1 Annual growth rate of real GDP per employed person	For developing countries like India, a large section of the society is dependent on agricultural activities and therefore increasing value addition in agriculture sector is

	value added and labour-intensive sectors		important. Sustainable agricultural practices could help in reducing costs and therefore increasing value addition.
	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to *decouple economic growth from environmental degradation*, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead	8.4.1 Material footprint, material footprint per capita, and material footprint per GDP 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	AES could help in decoupling agricultural production from environmental degradation. Policies of 'Zero Budget' agriculture announced by the Government of India could help in reducing input costs of agriculture.
10. Reduce inequality within and among countries	10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average	10.1.1 Growth rates of household expenditure or income per capita among the bottom 40 per cent of the population and the total population	Equitable distribution of farmlands acro
11. Make cities and human settlements inclusive, safe, resilient and sustainable	11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing	Urbanisation is one of the major drivers of diversion of farmlands for housing and infrastructure projects. Therefore instead of horizontal expansion, increasing productivity farmlands would be important. AES could help in degradation of farmlands and depletion of soil nutrients.

	11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	Discharge of untreated and/or partially treated domestic sewage and wastewater into water bodies / land is one of the major threats for pollution of ground and surface water resources in India. Irrigation water quality is deteriorating in many industrial pockets and peri-urban areas of India.
	11.A Support positive economic, social and environmental links between urban, per-urban and rural areas by strengthening national and regional development planning	11.A.1 Proportion of population living in cities that implement urban and regional development plans integrating population projections and resource needs, by size of city	Same as above
12. Ensure sustainable consumption and production patterns	12.1 Implement the 10-year framework of programmes on sustainable consumption and production, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries	12.1.1 Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies	Sustainable agricultural production is key for sustainable production and consumption. Moreover, leaching of chemicals from farmlands and residues of pesticides in food are public health hazards.
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP	Achieving AES could help in sustainable management of land, water and environment.

		12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	
	12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	12.4.1 Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement 12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment	AES could help in reducing application agro-chemicals as well as their release to environment
	12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities	12.7.1 Number of countries implementing sustainable public procurement policies and action plans	Public procurement of foodgrains and other crops from areas where AES is adopted could help adoption and propagation of AES in India.
	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula;	Increasing environmental awareness in general and AES in particular could help in adoption of sustainable agricultural practices.

		(c) teacher education; and (d) student assessment	
	12.C Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities	12.C.1 Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels	Providing free electricity to agriculture in many Indian states led to over pumping of groundwater and fall in groundwater table.
13. Take urgent action to combat climate change and its impacts*	13.2 Integrate climate change measures into national policies, strategies and planning	13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a	AES has potential to reduce emissions of greenhouse gases from agriculture and allied activities, especially methane and nitrous oxide. These gases have more ozone layer depletion potential than carbon dioxide.

		national adaptation plan, nationally determined contribution, national communication, biennial update report or other)	
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	14.1.1 Index of coastal eutrophication and floating plastic debris density	Agricultural runoff is the major source of nutrients in marine eco-system. Algal bloom and subsequently falling concentration of dissolved oxygen in marine water causes dead zones.
	14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels	14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	Leaving less freshwater for marine ecosystem and continuous discharging of domestic wastewater, sewage, industrial effluents, solid waste are the major causes of increasing pollution of sea water.
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type	
	15.2 By 2020, promote the implementation of sustainable management of all types of forests,	15.2.1 Progress towards sustainable forest management	Conversion of forest land for agricultural purposes is one the

	halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally		causes of diversions of forest land for other uses.
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area	Land degradation is a major threat for sustainable agriculture and also intensive agricultural practices lead to degradation of land.
	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	15.5.1 Red List Index	Agriculture provides many eco-system services which are important for conservation of bio-diversity. Moreover, agriculture is also dependent on biodiversity for pollination and natural control of harmful insects. Agricultural lands provide habitat for many species of fish, bird and animals. AES could help conservation of biodiversity.
	15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	

Source: Compiled from https://sustainabledevelopment.un.org/sdg1

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Appendix II

Description of Indicators of Sub-Indices of Agir-Environmental Sustainability Index (AESI) and Data Sources

No. of Indicators	Indicators of Sustainable Land Use Index (SLUI)	What does it measure?	Data Source(s)
1	Change in Average Land Not Available for Cultivation (as a percentage of Reporting Area of Land Utilization)$	Pressure on Agricultural Land from Alternative (Other) Uses	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
2	Average Fallow Land as Percentage of Reporting Area of Land Utilization	Buffer zone & supports Animal husbandry	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
3	Average Net Sown Area as Percentage of Reporting Area of Land Utilization$	Current Availability of Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
4	Change in Net Sown Area as Percentage of Reporting Area of Land Utilization$	Changing Current Availability of Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
5	Average Total (Gross) Cropped Area as Percentage of Reporting Area of Land Utilization$	Current Availability of Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
6	Average Cropping Intensity (Total or Gross Cropped Area /Net Sown Area*100)$	Pressure on Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
7	Change in Cropping Intensity (%)$	Changing Pressure on Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
8	Average Cultivated land as Percentage of Reporting Area of Land Utilization (%)$	Availability of Agricultural Land	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
9	Change in Cultivated Land as Percentage of Reporting Area of Land Utilization (%)$	Changing Availability of Agricultural Land (horizontal expansion of agriculture)	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
	Indicators of Sustainable Cropping Index (SCI)		
1	Average Area under Foodgrains as Percentage of Gross Cropped Area (%)$	Dominance of Foodgrains over Other crops	MoS&PI (2017 & Oth. Yrs.), RBI (2016) and DoE&S (2018 & Oth. Yrs)

2	Average Area under Coarse Cereals as Percentage of Gross Cropped Area	Less Input Intensive Cropping Practices (Crop Diversification)	MoS&PI (2017 & Oth. Yrs.), RBI (2016) and DoE&S (2018 & Oth. Yrs)
3	Average Area under Pulses as Percentage of Gross Cropped Area (%)	Nutritional Value of Crops & Natural Nitrogen Fixation (Self-sustainability of Soil Nutrients)	MoS&PI (2017 & Oth. Yrs.), RBI (2016) and DoE&S (2018 & Oth. Yrs)
4	Average Area under Sugarcane & Cotton as Percentage of Gross Cropped Area$	Water and chemical (fertilizer & pesticides) intensive cropping practices	MoS&PI (2017 & Oth. Yrs.), RBI (2016) and DoE&S (2018 & Oth. Yrs)
5	Change in Area under Sugarcane & Cotton as Percentage of Gross Cropped Area$	Changing water and chemical (fertilizers & pesticides) intensive cropping practices	MoS&PI (2017 & Oth. Yrs.), RBI (2016) and DoE&S (2018 & Oth. Yrs)
	Indicators of Sustainable Irrigation index (SII)		
1	Average Net Irrigated Area by Canals & Tanks as Percentage of NIA by All Sources (%)	Dependence on surface water for irrigation (less dependence on groundwater)	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
2	Change in Net Irrigated Area by Canals & Tanks as Percentage of NIA by All Sources (%)	Changing dependence on surface water for Irrigation (less dependence on groundwater)	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
3	Gross Irrigated Area (GIA) as Percentage of Gross-Cropped Area (%)$	Extent of irrigated agriculture vis-à-vis unirrigated / rain-fed agriculture	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
4	Change in Gross Irrigated Area as Percentage of Gross Cropped Area (%)$	Changing extent of irrigated agriculture	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
5	Average Irrigation Intensity (GIA/NIA*100) (NIA: Net Irrigated Area = GIA + Area Irrigated more than Once)$	Irrigation intensity	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
6	Change in Irrigation Intensity (%)$	Changing irrigation intensity	MoS&PI (2017 & Oth. Yrs.), RBI (2016)
7	Gross Area Irrigated under Foodgrains as Percentage of Total Area under Foodgrains$	Dependepnce on irrigation for food	MoS&PI (2017 & Oth. Yrs.), RBI (2016)

	Indicators of Sustainable Livestock Index (SLI)		
1	Number of Livestock Per 1000 Hectares of Reporting Area$	Livestosk density	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
2	Change in Number of Livestock Per 1000 hectare of Reporting Area$	Changing livestosk density	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
3	Number of Livestock Per 1000 hectare of Other uncultivated land excluding Fallow Land and Fallow lands other than current fallows$	Availability of grazing land (Common Property Resources)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
4	Change in Number of Livestock Per 1000 hectare of Other uncultivated land excluding Fallow Land and Fallow lands other than current fallows$	Changing availability of grazing land (Common Property Resources)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
5	Number of Livestock per 1000 ha of Arable Land$	Pressure of livestock on arable land (for fodder)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
6	Change in Number of Livestock per 1000 ha of Arable Land$	Changing pressure of livestock on arable land (for fodder)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
7	Number of Poultry Birds per 1000 ha of Arable Land$	Pressure and density of poultry birds on arable land (for feed)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
8	Change in Number of Poultry Birds per 1000 ha of Arable Land$	Changing pressure and density of poultry birds on arable land (for feed)	MoS&PI (2017 & Oth. Yrs.) and DoE&S (2018 & Oth. Yrs)
	Sustainable Agro-Chemical Index (SACI)		
1	Average Per Hectare Consumption of Fertilizer$	Intensity of fertilizer use	RBI (2016) & EPWRF ITS database
2	Average Consumption of Pesticides per 1000 ha of Gross Cropped Area (Kg/1000 ha)$	Intensity of pesticide use	RBI (2016) & EPWRF ITS database
	Indicators of Sustainable Farm Mechanization Index (SFMI)		
1	Electricity Consumption in Agriculture per Rs. Lakh of Agricultural GSDP (in KWh/Rs. Lakh of Agriculture GSDP)$	Energy intensity of agriculture	RBI (2016) & TERI (Yrs)
2	Average Number of Energized Pumpsets per 1000 ha of Net Sown Area$	Stress on groundwater	CWC (2002)

3	Average Number of Tractors per 1000 ha of Net Sown Area$	Extent of intensive (deep) tillage	IndiaStat Database
	Indicators of Population Pressure on Land Index (PPLI)		
1	Population Density (Person/ 1000 ha of Reporting Area of Land Utilization)$	Population pressure on land	MoS&PI (2017 & Oth Yrs.)
2	Average Population per 1000 ha of Arable Land$	Population pressure on arable land	MoS&PI (2017 & Oth Yrs.)
	Indicators of Sustainable Forest Index (SFI)		
1	Average Area under Forest Cover as Percentage of Geographical Area	Pressure on forest cover	FSI (Various Years)
2	Change in Share of Forest Cover in Geographical Area	Pressure on forest cover	FSI (Various Years)
3	Average Area under Tree Cover or Scrub as Percentage of Geographical Area	Pressure on forest cover	FSI (Various Years)
4	Change in Share of Tree Cover or Scrub in Geographical Area	Changing pressure on forest cover	FSI (Various Years)

Note: $-implies second method is used to standardize the indicator to get AX_{ij}

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