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Measuring farm sustainability index: priorities for sustaining livelihoods of farm households in Haryana, India

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The research investigated the challenges of agricultural sustainable development in Haryana by employing the Sustainable Livelihood Security Index (SLSI) as a comprehensive evaluative tool. The study integrates economic efficiency, ecological security and social equity dimensions through selected indicators and by utilizing Principal Component Analysis (PCA) to eliminate spatial variations among districts. The Economic Efficiency Index (EEI) reveals distinct agricultural performances with Karnal excelling in food production and Panchkula demonstrating efficient fertilizer use. The Ecological Security Index (ESI) highlights Gurgaon's significant land use practices and Panchkula's determinantal to forest conservation. The Social Equity Index (SEI) advancements in female literacy and healthcare. Integrating these three indices showed that Panchkula emerges as a paragon of overall sustainability, followed closely by Karnal, Sirsa and Gurgaon. Disparities in Nuh and Faridabad addressed the necessity for targeted interventions. These study findings offered to the policymakers about the crucial insights into district-specific needs which guiding them in the formulation of strategies for inclusive growth and sustainable development for each district's unique challenges and opportunities.

Keywords Sustainable development, Sustainable livelihood security index (SLSI), Principal component analysis, Haryana, Agriculture, Inclusive growth

Sustainable development goals can only be achieved by improving regional sustainability which is particularly relevant for developing countries like India. The origin of the concept of 'sustainable development (SD)' achieved global prominence in the late 1980s, with the World Commission on Environment and Development (WCED) report 'Our Common Future' i.e., the concept of sustainable development is defined as "development that caters to current needs without compromising the ability of future generations to meet their own requirements"[1]. In the context of India, research on sustainability and their dimensions has emerged gradually over the past decade with studies addressing sustainable forest management, methodologies for sustainability assessment, and various dimensions of sustainable agriculture[2–4]. India's agricultural sector holds a pivotal position in ensuring food and nutritional security, sustainable development, and poverty alleviation, having made significant strides in food grain production since the Green Revolution. However, challenges such as shrinking land holdings, shifts to non-profitable commercial crops, mounting debts, and vulnerability to market forces have surfaced, contributing to a decline in agricultural output and adverse ecological impacts[5]. The advancement of the SD concept has prompted the initiation of diverse environmental reforms globally over the past few decades[6]. The interrelated dimensions of SD, namely ecological, economic, and social, are integral to its holistic application[7]. The ecological dimension underscores a society's resilience in the face of disturbances and stresses, prioritizing the maintenance of a stable resource base and the cautious use of non-renewable resources[8]. Similarly, the economic aspect emphasizes the continuous production of goods and services to prevent detrimental sectoral imbalances, while the social dimension aims for equitable distribution, access to social services, gender parity, and political accountability[9].

The precise quantification of sustainability proves challenging due to its site-specific and dynamic nature[10]. Nonetheless, when specific parameters are selected, trends can be discerned, indicating stability, improvement, or decline[11]. The measurement of sustainability often involves evaluating changes in yields and total factor productivity, particularly in the context of agricultural practices[12]. Significant sustainability indicators which include pesticide use, inorganic fertilizer use and biodiversity advancement[13]. There is an abundance of

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approaches that have been developed to evaluate the sustainability of livelihoods at both the micro and macro levels.

Regional sustainability is influenced by three important factors i.e., economic, environmental, and social dimensions with that the concept of Sustainable Livelihood Security Index (SLSI), emerged and proposed by Swaminathan[7] that serves as an evaluative tool for comprehending and implementing SD. Sustainable livelihood security (SLS) is defined as the assurance of ecologically sound, economically efficient, and socially equitable livelihood options[14]. The intricate linkages between SLS and overarching welfare objectives such as poverty reduction and human development underscore the significance of SLSI for the sustainable development of agriculture (SDA)[4]. Consequently, the three-dimensional framework of SDA necessitates the integration of SLSI, comprising ecological security index (ESI), economic efficiency index (EEI), and social equity index (SEI) to discern the interplay and conflicts among the ecological, economic, and equity facets of SDA[15]. SLSI serves as a pragmatic and easily comprehensible instrument for evaluating sustainability, aiding in the formulation of policies and strategies for enhancing the security of rural livelihoods through the implementation of vital income-generating strategies and the enhancement of knowledge. It offers a unidimensional metric to assess country-specific information on multifaceted aspects of sustainable development, including economic, environmental, and social conditions[16]. This index is instrumental in realigning development programs and prioritizing development investments in highly susceptible areas.

Hickel[17] proposed a sustainable development index as a ratio of a development index to an ecological impact index, underscoring the complex interplay between development and environmental degradation. This study initially incorporated a diverse set of 20 indicators, primarily drawn from agricultural sustainability frameworks, alongside select parameters addressing the United Nations' SDGs. While various frameworks and models have previously been proposed for measuring agricultural sustainability, the complexity of the concept and the lack of consensus among researchers regarding its dimensions and indicators have posed challenges. Earlier delineations of the regions under consideration were based on soil, climate, physiography, effective rainfall, and soil groups. However, these classifications exhibit certain limitations in policy planning, thereby affecting the development of these districts. To date, no recent sustainability assessment has been conducted in this Northern region of India especially in Haryana based on economic, social, and ecological indicators. Given the significant influence of these indicators on the achievement of sustainable development goals, this research was conducted. Thus, Sustainable Livelihood Security Index (SLSI) is poised to aid in this process by providing comprehensive district-level information on economic, social, and environmental parameters, thereby facilitating informed decision-making and effective implementation strategies for inclusive growth, sustainable development, and the mitigation of inter-district imbalances. This paper endeavors to compute the district-wise SLSI for the state of Haryana, India, with the aim of providing valuable insights to planners and policymakers.

Materials and methods

Study area

The state of Haryana, positioned between latitudes 27° 39' and 30° 55' N and longitudes 74° 28' and 77° 36' E, covers an expanse of approximately 4.4 million hectares, constituting about 1.3 per cent of the country's total geographical area (TGA). With 22 administrative districts (Fig. 1) further divided into 126 tehsils, Haryana's landscape exhibits three key physiographic divisions: the Shivalik Hills, the Semi-Arid Plain, and the Flood Plains of the Yamuna River. These divisions manifest distinct characteristics, giving rise to the Northern Shivalik Region, Southern Haryana, and Yamuna-Ghaggar Plain, respectively. The regional climate showcases a range from semi-arid to sub-humid, featuring discernible variations between hot summers and cold winters. Haryana experiences an average annual rainfall spanning 320 to 800 millimeters, with temperature fluctuations between 10 °C and 45 °C throughout the year. Noteworthy agricultural practices in the state primarily center around the cultivation of staple crops, including wheat, rice, sugarcane, coarse cereals, and pulses, with a notable dependency on rainfed irrigation for a significant portion of agricultural endeavors. Agriculture, serving as the linchpin of Haryana's economic and developmental ambitions, engages a substantial segment of the state's populace, with a notable reliance on seasonal precipitation for sustenance. However, the insufficient vegetative cover and alarming deforestation rates in select regions contribute significantly to soil erosion and consequent reservoir siltation, leading to considerable degradation of water quality and disruption of the ecological equilibrium.

Selection of indicators

The process of choosing appropriate indicators to effectively represent the conditions of each dimension can be extensively discussed[18]. The selection of these indicators was informed by existing literature, prioritizing factors that are relevant, analytically sound, measurable, adaptable to various scales (such as farm, district, or country), and sensitive to both ecosystem processes and the influence of management practices and climate variations. While the rationale behind the inclusion of these indicators is clear, we acknowledge the need for a more detailed justification of both the inclusion and exclusion processes. In terms of inclusion, we prioritized indicators that provides more as comprehensive perspective on agricultural sustainability. For instance, economic efficiency indicators, such as crop yield, farm income, and resource use efficiency has selected to assess the financial sustainability of farming systems. Ecological indicators which include soil health and water use efficiency has incorporated to reflect the environmental sustainability of agriculture. Social equity indicators such as access to healthcare, education and social welfare, were included to capture the social dimension of sustainability. Regarding the exclusion of specific indicators that practical constraints such as data availability and relevance to the specific context of Haryana have carefully considered. Some indicators have significant in global sustainability discussions were excluded due to limited data availability or their less direct impact on the local sustainability challenges faced in Haryana. For example, indicators related to global trade and market access were not included as they were considered to have a less direct influence on local agricultural sustainability in the study region.

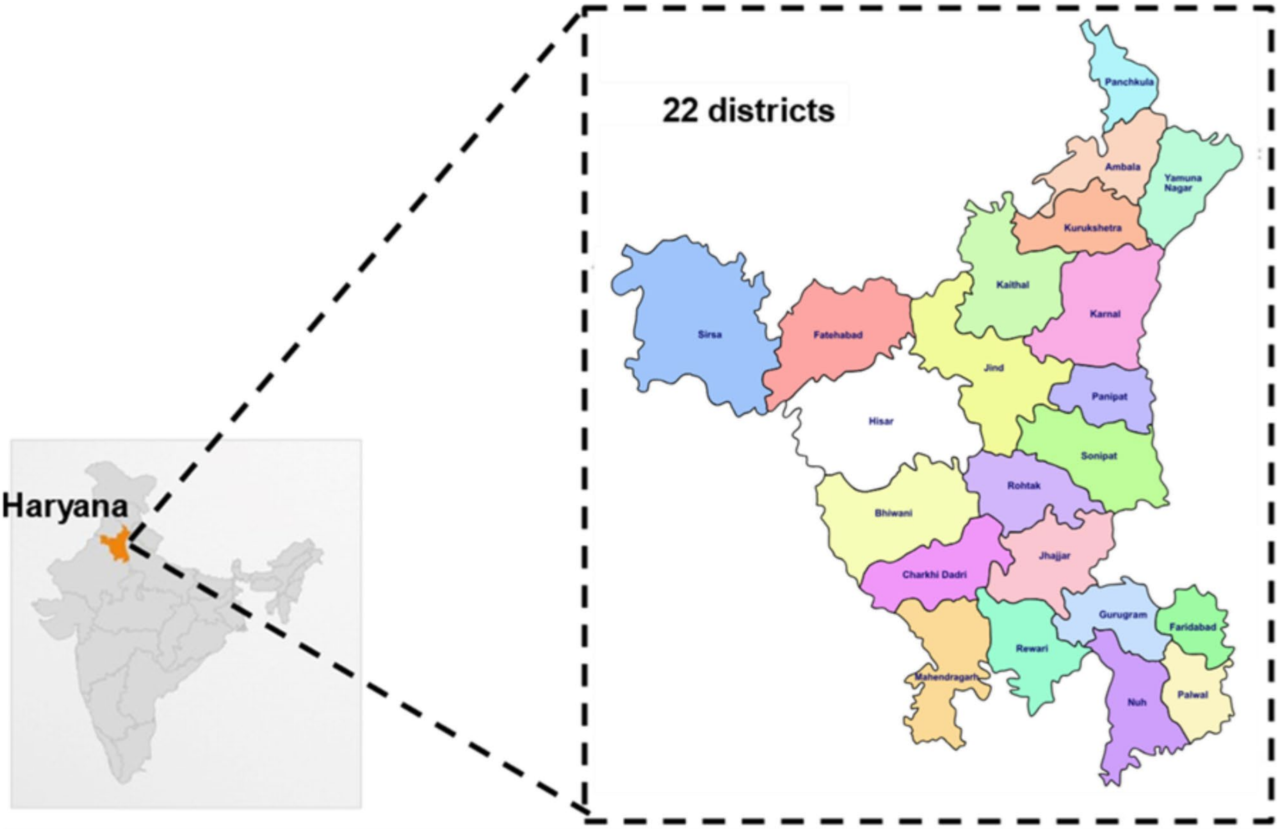

Fig. 1. Schematic representation of study area in map (Haryana state).(Source for the map: https://haryanacmoffice.gov.in/haryana-map. The map has been modified using appropriate tools and is not based on any copyrighted source).

The proposed indicators align with established suitability criteria, encompassing dimensions of social and policy relevance, analytical robustness, scalability, consideration of ecosystem processes, and responsiveness to variations in management and climate conditions[19]. These indicators were systematically categorized to align with the Sustainable Livelihood Security (SLS) framework across all 22 districts of the state. A comprehensive overview of the selected variables and their corresponding units of measurement has been described in Table 1.

Collection of data and its sources

The study based on secondary data from various government reports, including the State of Forest Report (Forest Survey of India), Dynamics of Groundwater Resources of India (Central Ground Water Board), and reports on the area, production, productivity, and prices of agricultural crops in Haryana. Data was also sourced from the Statistical Abstract of Haryana and final estimates of area, production, and average yield of principal crops in Haryana (Directorate of Economics and Statistics).

Principal component analysis

Principal Component Analysis (PCA), an enduring multivariate technique pioneered by Pearson[20] and further developed by Hotelling[21] served as a valuable tool for comprehending the spatial disparities at the district level, encompassing multiple interconnected multidimensional variables. Its selection is rooted in two fundamental objectives: firstly, the reduction of data dimensionality, and secondly, the interpretation of data in terms of principal components. PCA accomplishes this through the transformation of the initial variables into a fresh array of variables referred to as principal components. These principal components, which are uncorrelated, are systematically organized to ensure that the primary component encapsulates the utmost variability across all the original variables. Its utility extends to various domains, including spatial and longitudinal analyses[22]. Before initiating the PCA, the Kaiser-Meyer-Olkin (KMO) assessment is administered to evaluate the adequacy of the sample for the different indicators. The KMO statistics assess the strength of the associations among the variables, with values ranging from 0 to 1. A KMO value equal to or exceeding 0.600 signifies the suitability of the data for PCA, while values below the threshold are deemed inappropriate for the analysis[23].

Evaluation of index values

Given that indicators are subject to measurement in diverse units and scales, we applied normalization[24] for the purpose of standardizing the indicators. This normalization process was carried out to render the figures unit-free and to ensure uniformity in their values, thereby constraining them to a standardized range of 0 to 1. Before

Sl. no	Dimension/indicator	Unit	Reasons/importance for farm sustainability	Type of indicator	Year
Economic efficiency indicators					
1	Productivity of food grains	kg/ha	High crop productivity ensures food supply and supports farm income.	Positive (+)	2022-23
2	Fertilizer consumption	Tonnes	Lower fertilizer use reduces soil and water pollution, preserving soil health.	Negative (-)	2022-23
3	Pesticide consumption	Tonnes	Limited pesticide use protects beneficial organisms and farm biodiversity.	Negative (-)	2022-23
4	Average size of land holdings	Ha	Larger farms can manage resources more efficiently towards sustainable practices.	Positive (+)	2011
5	Net sown area	1000 ha	Maximizing productive land use is essential for food production and income.	Positive (+)	2022-23
6	Milk yield	Kgs	Higher milk yield supports farmers' income and provides economic security.	Positive (+)	2022-23
7	Population served per bank	Nos.	More accessible banking supports farmers' financial needs and investments.	Negative (-)	2022-23
8	Per capita income (current price)	Rs/annum	Higher income allows farmers to invest in sustainable practices	Positive (+)	2022-23
9	Annual rainfall	MM	Adequate rainfall is essential for crop growth without relying heavily on irrigation.	Positive (+)	2022-23
10	State-owned warehouses	Lakh MT	Good storage reduces post-harvest losses and stabilizes farmers' income.	Positive (+)	2022-23
Ecological security indicators					
11	Cropping intensity	%	Lower intensity can prevent soil exhaustion, supporting long-term productivity.	Negative (-)	2022-23
12	Population density	no./sq.km	Lower population pressure reduces strain on resources enables sustainable farm use.	Negative (-)	2011
13	Livestock density	no./sq.km	Balanced livestock density avoids overgrazing, preserving land for crops.	Negative (-)	2012
14	Total forest area	Sq. Km.	Forest areas contribute to stable ecosystems, which support sustainable agriculture.	Positive (+)	2022-23
15	Total cropped area	1000 ha	More cropped land enables more food production, crucial for farm sustainability.	Positive (+)	2022-23
16	Deviation of annual rainfall	C.V	Less rainfall variation helps maintain stable crop yields, supporting farm resilience.	Negative (-)	2022-23
17	Groundwater development stress	Draft (%)	Lower stress means groundwater usage in sustainably enables future water access.	Negative (-)	2022-23
18	Groundwater resource (Aquifer)	Depth (m)	Good groundwater levels ensure reliable water supply for farming activities.	Positive (+)	2022-23
Social equity indicators					
19	Female literacy persons	Nos.	Higher female literacy can boost farm productivity through better skills and choices.	Positive (+)	2022-23
20	Infant death /mortality	Nos.	Lower mortality reflects healthier families, supporting stable and productive farms.	Negative (-)	2022-23
21	Road lenth (km)	Km	Better roads improve access to markets, boosting farmers' income opportunities.	Positive (+)	2022-23
22	Electricity connections (Agri.)	Nos.	Electricity access enables efficient irrigation and other farm operations.	Positive (+)	2022-23
23	No. of PACS credit societies	Nos.	Credit access helps farmers invest in sustainable practices	Positive (+)	2022-23
24	Employees of organized sectors	Nos.	Jobs in organized sectors can supplement farm income and reduce rural poverty.	Positive (+)	2022-23
25	Govt. recognised school	Nos.	More schools provide better education for rural families, enhancing farm skills.	Positive (+)	2022-23
26	Incidences of IPC crime	Nos.	Low crime rates create a stable environment, encouraging investment in agriculture.	Negative (-)	2022-23
27	Groundwater availability	ha-m	Reliable groundwater supports crops during dry periods, ensuring resilience.	Positive (+)	2022-23
28	Teacher pupil ratio in primary	%	Balanced ratios ensure quality education, contributing to skilled farming.	Negative (-)	2022-23

Table 1. Selected indicators with their corresponding measurement unit, their functional relationship with sustainability.

embarking on this normalization process, it becomes imperative to discern the functional association between the indicators and the concept of sustainability. Such a relationship can assume two forms: (a) a positive relation wherein sustainability enhances as the indicator value rises, or (b) a negative correlation wherein sustainability diminishes as the indicator value increases.

To organize the collected data for each sustainability dimension, a structured rectangular matrix was formulated, where rows denoted the districts and columns symbolized the respective indicators. Considering the existence of L districts (j = 1, 2, …, L) and the collection of K indicators (i = 1, 2, …, K), the resulting table comprised L rows and K columns. Represented as x_{ij}, the value of the i_{th} indicator pertaining to the j_{th} district was delineated.

$$Z_{ij} = \frac{x_{ij} - \text{Min}\{x_{ij}\}}{\text{Max}\{x_{ij}\} - \text{Min}\{x_{ij}\}} \quad (\text{Positive relationship}) \tag{1}$$

$$Z_{ij} = \frac{\text{Min}\{x_{ij}\} - x_{ij}}{\text{Max}\{x_{ij}\} - \text{Min}\{x_{ij}\}} \quad (\text{Negative relationship}) \tag{2}$$

where Min$\{x_{ij}\}$and Max$\{x_{ij}\}$ are the minimum and maximum value of i_{th} indicator among all the L districts respectively.

$$ESI_j = \sum_{1}^{i} (w_i \times Z_{ij}) \tag{3}$$

where $\sum_{1}^{i} w_i = 1$ where ESI_j represents the ESI for j^{th} district and w_i denotes the weight associated with the i_{th} indicator included for computation of ESI.

For estimating the weight[25] associated with the indicator

$$w_i = \frac{c}{\sqrt{\mathrm{Var}\ (Z_{ij})}} \tag{4}$$

where C is a standardized constant such that

$$C = \sum_{j=1}^{k} \frac{1}{\sqrt{\mathrm{var}(Z_{ij})}} \tag{5}$$

Adopting this approach for selecting the weights guarantees that an extensive variation in any single indicator would not excessively overshadow the impact of the other indicators, thereby preventing any distortion in the inter-district evaluations. Similar to the calculation of ESI_j, the values for EEI_j (EEI) and SEI_j (SEI) were determined. Consequently, the sustainability indices (ESI, EEI, and SEI) evaluated within the range of 0 to 1, with 1 denoting optimal sustainability and 0 indicating a lack of sustainability within the ecosystem.

Therefore, Sustainable Livelihood Security Index (SLSI) was computed as follows.

$$SLSI_j = W_{ESI} * ESI_j + W_{EEI} * EEI_j + W_{SEI} * SEI_j \tag{6}$$

Results and discussion

PCA factor loading of associated variables and their relevance

The Principal Component Analysis (PCA) results has used to reduce dimensionality and identify the key factors influencing the farm sustainability indices across the districts of Haryana The factor loadings of associated 28 indicators for the SLSI are provided in Table 2. The first five principal components explain 77.921% of the overall variance of the original data set, of which the first two components take a significant share of 51.094%. The eigenvalues, percentage variability, and cumulative variance of each PC are elicited and the amount of variability accounted for by PCA in terms of PC1, PC2, PC3, PC4, and PC5 was 34.067%, 17.027%, 10.772%, 9.100%, and 6.955%, respectively. Seven variables were found to be high association from PC 1 i.e., fertilizer consumption (0.933), average size of land holdings (0.916), net sown area (0.865), capacity of state-owned warehouses (0.838), total cropped area (0.901), road length (0.864) and groundwater availability (0.851) and contributed maximum variability (34.067%). PC2 for five variables i.e., population served per bank (-0.575), per capita income at current price (0.747), population density (0.694), employees of organized sectors (0.573) and incidences of IPC crime (0.922). PC3 is primarily associated with population served per bank (0.660), deviation of annual rainfall (-0.589), groundwater resource (-0.607) and teacher pupil ratio in primary (0.655). The fourth principal component (PC4) is associated with annual rainfall (0.731), livestock density (-0.645) and total forest area (0.755). Similarly, PC5 shows higher associated with productivity of food grains (0.463), groundwater development stress (0.460) and teacher pupil ratio in primary (0.423).

PC1 has predominantly been driven by economic efficiency indicators, such as crop yield, farm income and resource utilization. It reflects the financial viability and resource optimization of agricultural systems. In practical terms, districts with high scores on PC1, like Sirsa and Karnal, exhibit better economic sustainability in agricultural practices. These districts demonstrate robust agricultural productivity and resource efficiency, which are crucial for ensuring the long-term sustainability of farm households. Whereas PC2 captured aspects related to ecological security, influenced by indicators such as soil health, water usage efficiency, and overall environmental management. It reflects the ecological resilience of farming systems, which is necessary for maintaining productivity while minimizing adverse environmental impacts. Districts with high scores on PC2, such as Hisar and Fatehabad, perform better in terms of ecological stewardship. These areas are characterized by sustainable agricultural practices that prioritize environmental conservation, highlighting the need for policies focused on preserving natural resources for future generations. PC3 focused on social equity, with indicators such as access to education, healthcare, sanitation, and overall quality of life for farm households. A higher score on PC3 indicates that a district performs well in terms of social inclusion and the equitable distribution of resources, ensuring that the benefits of agricultural growth are shared across all sections of society. Karnal, for example, scores highly on PC3, pointing to its strong social welfare systems and equitable access to essential services. This reflects the importance of addressing social equity in promoting sustainable livelihoods for farming communities. The cumulative contribution of these three-component economic efficiency, ecological security, and social equity provides a holistic view of sustainability in Haryana's agriculture. The PCA results reveal that economic efficiency and ecological security are the dominant drivers of farm sustainability in most districts, but social equity plays a significant role, especially in districts like Karnal, where social programs support inclusive growth. By considering the practical implications of these components, we can better understand how different districts can improve their sustainability outcomes and address specific challenges related to economic, ecological, and social dimensions of agricultural development.

Economic efficiency index (EEI)

The data presented in Table 3 provides the overall economic efficiency which has evaluated across several dimensions, such as food grain productivity, fertilizer and pesticide consumption, average farm size, net sown area, milk yield, banking services, per capita income, annual rainfall, and warehouse capacity. These diverse indicators contribute to an overall understanding of the economic performance of the region. Karnal (1.000) stands out for its exceptional performance in food grain productivity which reflecting its strong agricultural stability. Panchkula (1.000) excels in fertilizer consumption which indicating the efficient resource use. Similarity,

Components	PC1	PC2	PC3	PC4	PC5
Eigen values	9.539	4.768	3.016	2.548	1.947
% of variance	34.067	17.027	10.772	9.1	6.955
Cumulative %	34.067	51.094	61.866	70.966	77.921
Economic efficiency indicators					
Productivity of food grains	0.682	0.298	-0.204	0.315	0.463
Fertilizer consumption	0.933	0.003	-0.072	-0.005	0.157
Pesticide consumption	0.793	0.24	0.03	0.066	0.185
Average size of land holdings	0.916	-0.113	-0.051	-0.069	-0.262
Net sown area	0.865	-0.144	0.137	-0.122	-0.356
Milk yield	0.527	-0.248	-0.14	0.168	-0.239
Population served per bank	0.047	-0.575	0.660	-0.329	0.21
Per capita income at current price	-0.341	0.747	-0.233	0.081	-0.136
Annual rainfall	-0.414	0.267	0.033	0.731	0.323
Capacity of state-owned warehouses	0.838	0.121	-0.124	-0.041	0.104
Ecological security indicators					
Cropping intensity	0.144	0.461	0.065	-0.348	-0.017
Population density	-0.508	0.694	0.155	-0.207	0.074
Livestock density	-0.242	0.406	0.274	-0.645	0.29
Total forest area	-0.245	-0.037	-0.303	0.755	0.045
Total cropped area	0.901	-0.08	0.075	-0.123	-0.315
Deviation of annual rainfall	-0.098	-0.288	-0.589	0.135	-0.329
Groundwater development stress	0.335	0.386	-0.48	-0.316	0.460
Groundwater resource	0.049	-0.086	-0.607	-0.473	0.100
Social equity indicators					
Female literacy persons	0.217	0.9	0.129	0.009	-0.239
Infant death /mortality	0.179	0.402	0.663	0.229	-0.02
Road Lenth	0.864	-0.153	0.206	0.045	-0.277
Number of agricultural electricity connections	0.797	0.076	-0.353	-0.162	0.283
Number of primary agricultural credit societies	0.693	0.141	-0.114	0.152	0.393
Employees of organized sectors	0.543	0.573	0.294	0.207	-0.308
Govt. recognised school	0.65	-0.144	0.297	0.264	0.184
Incidences of IPC crime	-0.059	0.922	0.183	0.026	-0.171
Groundwater availability	0.851	0.094	0.034	0.102	0.132
Teacher pupil ratio in primary	-0.023	-0.462	0.655	0.099	0.423

Table 2. Performance of economical, ecological and social indicators in terms of factor loading/eigenvector values in principal component analysis (PCA). Note: PC stands for principal component.

Sirsa (1.000) demonstrates the highest pesticide consumption which may suggest challenges in pest management that could require attention to more sustainable practices. The average farm size also varies significantly among districts. Larger land holdings are observed in districts like Karnal (0.729) and Sirsa (1.000) that suggesting more favorable conditions for large-scale farming, while districts such as Charkhi Dadri (0.161) and Faridabad (0.097) report smaller average farm sizes, possibly due to different agricultural practices or land constraints. Gurgaon (1.000) emerged as a leader, indicating efficient land use practices in the context of net sown area, benefits from a high per capita income showing its economic prosperity. Meanwhile, Panchkula highlighted strong performance in milk yield (0.953) and the capacity of state-owned warehouses (1.000) exhibiting its diverse agricultural strengths and storage infrastructure. When aggregating all these indicators into the Economic Efficiency Index (EEI), a clearer picture of each district's overall economic health calculated. Districts like Karnal (0.511), Kurukshetra 0.532) and Panchkula (0.528) are among the top performers, reflecting balanced and significant economic performance across various indicators. While, districts such as Charkhi Dadri (0.368), Mahendragarh (0.393) and Palwal (0.260) exhibited lower values indicating to areas where targeted interventions could drive improvement.

Ecological security index (ESI)

A district-wise evaluation of Ecological Security (Table 4) by examining various indicators that reflect the ecological balance and sustainability of agricultural practices in each district. Each district's ecological security has measured using indicators such as cropping intensity, population and livestock density, forest cover, total cropped area, deviation of annual rainfall, groundwater development stress, and groundwater resources. Panchkula (1.000) emerges as a leading district in terms of ecological security particularly excelling in livestock

District	EE1	EE2	EE3	EE4	EE5	EE6	EE7	EE8	EE9	EE10	EEI
Ambala	0.767	0.688	0.490	0.361	0.337	0.507	0.805	0.218	0.589	0.143	0.490
Bhiwani	0.233	0.695	0.611	0.981	0.730	1.000	0.489	0.085	0.000	0.114	0.494
Charkhi Dadri	0.000	0.880	0.823	0.161	0.240	0.595	0.514	0.080	0.389	0.000	0.368
Faridabad	0.224	0.995	0.958	0.097	0.022	0.288	0.686	0.414	0.542	0.128	0.435
Fatehabad	0.938	0.339	0.770	0.587	0.528	0.558	0.639	0.123	0.547	0.637	0.566
Gurgaon	0.511	0.973	0.996	0.039	0.256	0.339	1.000	1.000	0.721	0.019	0.585
Hisar	0.615	0.377	0.088	0.826	0.841	0.655	0.613	0.100	0.417	0.582	0.511
Jhajjar	0.432	0.852	0.886	0.194	0.299	0.520	0.679	0.174	0.644	0.011	0.469
Jind	0.761	0.360	0.631	0.594	0.623	0.544	0.473	0.110	0.490	0.524	0.511
Kaithal	0.855	0.426	0.387	0.710	0.469	0.548	0.608	0.139	0.184	0.528	0.485
Karnal	1.000	0.299	0.000	0.729	0.477	0.567	0.751	0.162	0.529	0.596	0.511
Kurukshetra	0.998	0.419	0.515	0.471	0.323	0.581	0.796	0.186	0.435	0.596	0.532
Mahendragarh	0.214	0.838	0.943	0.342	0.348	0.353	0.528	0.092	0.249	0.018	0.393
Nuh	0.399	0.914	0.973	0.148	0.235	0.455	0.000	0.000	0.643	0.038	0.381
Palwal	0.164	0.748	0.684	0.000	0.221	0.041	0.363	0.038	0.339	0.001	0.260
Panchkula	0.406	1.000	0.948	0.097	0.000	0.465	0.953	0.262	1.000	0.152	0.528
Panipat	0.694	0.736	0.230	0.181	0.202	0.064	0.732	0.352	0.384	0.257	0.383
Rewari	0.289	0.820	1.000	0.245	0.278	0.572	0.724	0.188	0.274	0.035	0.443
Rohtak	0.383	0.732	0.929	0.297	0.350	0.000	0.740	0.147	0.369	0.173	0.412
Sirsa	0.780	0.000	0.303	1.000	1.000	0.567	0.614	0.115	0.091	1.000	0.547
Sonipat	0.666	0.540	0.452	0.432	0.348	0.628	0.734	0.190	0.532	0.341	0.486
Yamunanagar	0.968	0.426	0.426	0.323	0.243	0.548	0.696	0.135	0.835	0.149	0.475

Table 3. District wise indices values of the economic efficiency indicators. Note: EE1 = productivity of food grains; EE2 = fertilizer consumption; EE3 = pesticide consumption; EE4 = average size of land holdings; EE5 = net sown area; EE6 = milk yield; EE7 = population served per bank; EE8 = per capita income at current price; ES9 = annual rainfall; ES10= capacity of state owned warehouses; EEI = economic efficiency index.

density and forest cover. These strong ecological factors contribute to Panchkula's overall ESI value of 0.631 securing it as one of the more environmentally sustainable districts. Sirsa also performs well achieving top scores in population density (1.000) and total cropped area (1.000), leading to a high ESI of 0.641 although has groundwater development stress (0.483) indicates potential pressure on water resources. Similarly, Faridabad secured the lowest in ecological security with several key indicators such as cropping intensity (0.000), livestock density (0.000), and total forest area (0.113) revealing significant ecological challenges that makes the worse value of ESI (0.233) which suggesting a need for focused ecological interventions, particularly in enhancing forest cover and reducing stress on groundwater resources.

The ESI values for other districts such as Bhiwani (0.629) and Fatehabad (0.588) showed relatively balanced ecological performance. Bhiwani's high population density (0.982) and groundwater development stress (0.681) while Fatehabad's strong deviation in annual rainfall (0.776) and cropping intensity (0.673) suggest agricultural resilience. However, both districts will need to address certain ecological vulnerabilities to ensure long-term sustainability. Mahendragarh (0.598) has primarily driven by its high groundwater resource score (1.000), which is a significant ecological advantage. However, the district's low forest area (0.065) and relatively high population density (0.915) pose ecological concerns that could affect the overall environmental balance. In the contrast, Gurgaon has strong performance in rainfall deviation (0.954) and groundwater resource availability (0.594). Despite these strengths, the district's relatively low total cropped area (0.097) and population density (0.579) limit its overall ecological security, reflected in an ESI of 0.522. Also districts such as Faridabad (0.233) and Palwal (0.477) with low ESI scored highlighted the need for urgent ecological interventions, particularly in the areas of forest regeneration and groundwater management.

Social equity index (SEI)

Table 5 provides a detailed analysis of Social Equity across various districts evaluating on factors such as female literacy, infant mortality, road infrastructure, access to agricultural electricity connections, credit societies, employment in organized sectors, school availability, crime incidences, groundwater availability, and teacher-pupil ratios. Karnal (0.745) stands out with the highest Social Equity Index by excelling in significant sectors such as agricultural electricity connections (1.000), access to primary agricultural credit societies (1.000), teacher-pupil ratios (0.741) and also performing well in terms of female literacy (0.687) and government-recognized schools (0.727) has reflected its strong social infrastructure and commitment to equity in education and agriculture. Similarly, Hisar (0.626) achieves a second highest SEI by its exceptional road length (1.000) and strong presence in organized sector employment (1.000) which contributing to its overall social stability and infrastructure development. Jind's notable achievements include a perfect score in groundwater availability (1.000), alongside significant progress in road infrastructure (0.565) and female literacy (0.478). Sirsa excels

District	ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ESI
Ambala	0.770	0.806	0.675	0.068	0.284	0.538	0.610	0.192	0.493
Bhiwani	0.732	0.982	0.886	0.102	0.675	0.418	0.681	0.554	0.629
Charkhi Dadri	0.858	0.982	0.372	0.006	0.181	0.887	0.536	0.587	0.551
Faridabad	0.000	0.000	0.000	0.113	0.109	0.674	0.601	0.363	0.233
Fatehabad	0.673	0.968	0.718	0.076	0.545	0.776	0.382	0.568	0.588
Gurgaon	1.000	0.579	0.578	0.161	0.097	0.954	0.216	0.594	0.522
Hisar	0.721	0.937	0.580	0.096	0.849	0.941	0.778	0.094	0.624
Jhajjar	0.849	0.897	0.700	0.040	0.304	0.628	1.000	0.019	0.555
Jind	0.813	0.911	0.235	0.113	0.492	0.968	0.667	0.266	0.558
Kaithal	0.660	0.925	0.517	0.122	0.489	0.076	0.192	0.631	0.451
Karnal	0.670	0.862	0.659	0.136	0.489	0.943	0.391	0.391	0.568
Kurukshetra	0.755	0.847	0.498	0.045	0.338	0.707	0.000	0.835	0.503
Mahendragarh	0.818	0.915	0.581	0.065	0.331	0.376	0.699	1.000	0.598
Nuh	0.892	0.804	0.627	0.142	0.139	1.000	0.827	0.214	0.581
Palwal	0.980	0.783	0.261	0.000	0.106	0.755	0.737	0.192	0.477
Panchkula	0.957	0.849	1.000	1.000	0.000	0.000	0.921	0.321	0.631
Panipat	0.797	0.697	0.262	0.040	0.206	0.918	0.349	0.392	0.458
Rewari	0.929	0.878	0.676	0.059	0.154	0.058	0.596	0.622	0.497
Rohtak	0.947	0.857	0.683	0.048	0.186	0.783	0.984	0.000	0.561
Sirsa	0.699	1.000	0.845	0.057	1.000	0.598	0.483	0.444	0.641
Sonipat	0.625	0.822	0.514	0.184	0.389	0.199	0.680	0.194	0.451
Yamunanagar	0.753	0.821	0.766	0.564	0.241	0.710	0.485	0.215	0.569

Table 4. District wise indices values of the ecological security indicators. Note: ES1 = cropping intensity; ES2 = population density; ES3 = livestock density; ES4 = total forest area; ES5 = total cropped area; ES6 = deviation of annual rainfall; ES7 = groundwater development stress; ES8 = groundwater resource; ESI = ecological security index.

in both road length (0.889) and groundwater availability (0.646), reflecting a balanced approach to social development and infrastructure. Therefore, these districts i.e., Jind (0.627) and Sirsa (0.666) also demonstrate strong performance in social equity. Similarly, districts such as Faridabad (0.309) and Charkhi Dadri (0.351) showed significant challenges in terms of social equity. Faridabad scores poorly in various factors such as road length (0.000), agricultural electricity connections (0.053), and primary agricultural credit societies (0.000) that contributing to its low overall SEI (0.309) along with district Charkhi Dadri struggles in terms of female literacy (0.000) and access to primary agricultural credit societies (0.185) which resulted in its poor overall SEI (0.351) showed significant social gaps that require focused interventions to enhance equity and access to basic services. Nuh registers the lowest SEI (0.271) primarily due to low scores in female literacy (0.014), infant mortality (0.013) and road length (0.360). Despite a strong performance in organized sector employment (1.000) Nuh faces substantial social challenges, especially in educational and infrastructural areas, underscoring the need for targeted policy measures to uplift its social equity standing. Furthermore, the results revealed that while some districts like Sirsa, Hisar, and Karnal showed commitment to equitable social development other like Faridabad, Charkhi Dadri, and Nuh highlighted areas where urgent attention is needed.

Sustainable livelihood security index (SLSI)

The district-wise indices (Table 6) for the Sustainable Livelihood Security Index (SLSI) evaluated by summation of the Economic Efficiency Index (EEI), Ecological Security Index (ESI) and Social Equity Index (SEI) along with their respective calculated weights. Also, by using the radar chart (Fig. 2) helps to compare the performance of districts across four indices. They showed that Sirsa (0.629) leads with the highest SLSI score as strong performance across the three dimensions. Karnal (0.625) follows closely second highest SLSI driven by its impressive performance in social equity (0.745)which is the highest among all districts. Further Hisar (0.580) also stands out with an SLSI score showed balanced performance as evidence followed by Fatehabad (0.568) and Yamunanagar (0.551) also secured good SLSI score highly. Conversely, Faridabad and Palwal has exhibited the lowest SLSI scores as 0.318 and 0.373 respectively because Faridabad faces major challenges in ecological security (0.233) and social equity (0.309) suggesting that both environmental management and social infrastructure required attention. Palwal similarly struggles in economic efficiency (0.260) and social equity (0.410) which reflecting the need for targeted interventions in these areas to improve its livelihood security. Similarly, Nuh (0.415) also showed very low SLSI scores mainly due to weak performance in social equity (0.271) and suggesting that needs to focus on social development indicators like education and healthcare to improve its overall sustainability. Districts such as Gurgaon (0.492) and Panchkula (0.485) have performed moderately in overall sustainability. This mainly due to that Gurgaon excels in economic efficiency (0.585),but lags in social equity (0.375) which highlighting an imbalance between economic growth and social welfare whereas Panchkula

District	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10	SEI
Ambala	0.544	0.761	0.561	0.327	0.753	0.489	0.710	0.754	0.463	0.815	0.618
Bhiwani	0.365	0.741	0.537	0.368	0.309	0.481	0.685	0.796	0.383	0.741	0.541
Charkhi Dadri	0.000	1.000	0.312	0.142	0.185	0.000	0.000	1.000	0.054	0.815	0.351
Faridabad	1.000	0.549	0.000	0.053	0.000	0.330	0.018	0.280	0.013	0.852	0.309
Fatehabad	0.225	0.844	0.650	0.533	0.296	0.254	0.455	0.870	0.626	0.741	0.549
Gurgaon	0.835	0.321	0.180	0.212	0.062	0.672	0.365	0.000	0.102	1.000	0.375
Hisar	0.764	0.000	1.000	0.203	0.494	1.000	0.915	0.402	0.627	0.852	0.626
Jhajjar	0.342	0.934	0.520	0.104	0.198	0.244	0.278	0.706	0.318	0.778	0.442
Jind	0.478	0.754	0.565	0.583	0.296	0.463	0.660	0.769	1.000	0.704	0.627
Kaithal	0.302	0.835	0.535	0.771	0.383	0.354	0.414	0.811	0.646	0.815	0.587
Karnal	0.687	0.486	0.659	1.000	1.000	0.750	0.727	0.463	0.936	0.741	0.745
Kurukshetra	0.341	0.824	0.372	0.537	0.802	0.349	0.742	0.709	0.337	0.815	0.583
Mahendragarh	0.275	0.963	0.340	0.399	0.198	0.295	0.637	0.820	0.184	0.889	0.500
Nuh	0.014	0.013	0.360	0.041	0.173	0.192	1.000	0.856	0.057	0.000	0.271
Palwal	0.200	0.884	0.288	0.199	0.198	0.132	0.439	0.726	0.331	0.704	0.410
Panchkula	0.087	0.886	0.101	0.000	0.049	0.032	0.099	0.893	0.000	0.852	0.300
Panipat	0.458	0.675	0.263	0.421	0.346	0.257	0.096	0.512	0.286	0.815	0.413
Rewari	0.304	0.906	0.418	0.408	0.247	0.190	0.483	0.779	0.219	0.815	0.477
Rohtak	0.430	0.914	0.399	0.030	0.185	0.590	0.074	0.590	0.250	0.778	0.424
Sirsa	0.466	0.798	0.889	0.811	0.358	0.326	0.830	0.756	0.646	0.778	0.666
Sonipat	0.674	0.334	0.654	0.457	0.333	0.604	0.616	0.601	0.719	0.815	0.581
Yamunanagar	0.546	0.826	0.226	0.457	0.506	0.385	0.991	0.671	0.598	0.741	0.595

Table 5. District wise indices values of the social equity indicators. Note: SEI = female literacy persons; SE2 = Infant death /mortality; SE3 = road lenth; SE4 = number of agricultural electricity connections; SE5 = number of primary agricultural credit societies; SE6 = employees of organized sectors; SE7 = Govt. recognised school; SE8 = Incidences of IPC crime; SE9 = groundwater availability; SE10 = teacher pupil ratio in primary; SEI = social equity index.

performed well in ecological security (0.631) but struggles with social equity (SEI = 0.300) that pointing to potential areas for policy intervention. The overall index values of four indices for Haryana (Fig. 3) were as follows i.e., Economic Efficiency Index (0.467), Ecological Security Index (0.534), Social Equity Index (0.500) and Sustainable Livelihood Security Index (SLSI) at 0.501. These values indicated a balanced performance across the indices only highlighting the need for improvement in economic efficiency and social equity but showing relatively stronger outcomes in ecological security and sustainable livelihoods of farm households in Haryana.

Table 7 revealed the rankings of the different districts based on the calculated scores of Economic Efficiency Index (EEI), Ecological Security Index (ESI), Sustainable Security Index (SSI), and sustainable Livelihood Security Index (SLSI). They provide a detailed assessment of the farm sustainability performance of every district. The rankings are further categorized into four distinct categories: least sustainable, moderately sustainable, sustainable, and highly sustainable. Each of these categories are displayed clearly on the study area map (Fig. 4). Thus, SLSI provides valuable insights into the strengths and weaknesses of different districts in Haryana i.e., districts like Sirsa, Karnal, and Hisar show strong, balanced performances, others like Faridabad and Palwal need significant improvements in ecological and social dimensions. The study revealed that only eleven districts out of 22 districts in Haryana (about 1/2th) had an index of SLSI above 0.5, while remaining had SLSI value lower than 0.49 that indicates Haryana is sustainable. Similar findings have been reported by Bharti and Sen[26] found that only about 1/4th of Bihar's districts scored above 0.5 on the sustainable Livelihood Security Index (SLSI), while around half had SLSI values below 0.4 and suggests that overall south Bihar exhibited better agricultural sustainability than north Bihar.

As presented in Table 8, about 27.14 million people in the state of Haryana are situated within areas classified as 'less sustainable' and 'moderately sustainable,' encompassing 51.8% and 34% of the state's total geographical area, respectively. These regions face vulnerabilities related to climate change, forest cover loss, and ecosystem service degradation. The 'moderately sustainable' category includes a population of 20.74 million. This data underscores the necessity for a critical review of policy interventions and development strategies in the state, with a primary emphasis on districts falling under the 'less sustainable' and 'moderately sustainable' SLSI categories. Addressing these concerns is imperative for achieving inclusive growth and ensuring the well-being of the residents.

Policy implications and conclusion

The study integrated economic efficiency, ecological security, and social equity dimensions by selecting suitable indicators and employing Principal Component Analysis (PCA) to eliminate spatial variations among districts to analysis the sustainable development in Haryana by using the Sustainable Livelihood Security Index (SLSI) as

District	EEI		ESI		SSI		SLSI
	Mean	Weight	Mean	Weight	Mean	Weight	
Ambala	0.490	0.318	0.493	0.263	0.618	0.419	0.544
Bhiwani	0.494	0.236	0.629	0.319	0.541	0.445	0.558
Charkhi Dadri	0.368	0.373	0.551	0.352	0.351	0.275	0.428
Faridabad	0.435	0.315	0.233	0.404	0.309	0.280	0.318
Fatehabad	0.566	0.368	0.588	0.306	0.549	0.325	0.568
Gurgaon	0.585	0.303	0.522	0.361	0.375	0.337	0.492
Hisar	0.511	0.400	0.624	0.309	0.626	0.291	0.580
Jhajjar	0.469	0.357	0.555	0.280	0.442	0.363	0.483
Jind	0.511	0.416	0.558	0.227	0.627	0.357	0.563
Kaithal	0.485	0.368	0.451	0.274	0.587	0.358	0.512
Karnal	0.511	0.278	0.568	0.311	0.745	0.410	0.625
Kurukshetra	0.532	0.370	0.503	0.254	0.583	0.376	0.544
Mahendragarh	0.393	0.345	0.598	0.326	0.500	0.328	0.495
Nuh	0.381	0.337	0.581	0.345	0.271	0.318	0.415
Palwal	0.260	0.368	0.477	0.273	0.410	0.358	0.373
Panchkula	0.528	0.346	0.631	0.320	0.300	0.335	0.485
Panipat	0.383	0.343	0.458	0.278	0.413	0.379	0.415
Rewari	0.443	0.330	0.497	0.296	0.477	0.374	0.471
Rohtak	0.412	0.373	0.561	0.272	0.424	0.356	0.457
Sirsa	0.547	0.244	0.641	0.310	0.666	0.445	0.629
Sonipat	0.486	0.373	0.451	0.255	0.581	0.372	0.512
Yamunanagar	0.475	0.292	0.569	0.354	0.595	0.354	0.551
Overall index	0.467		0.534		0.500		0.501

Table 6. District wise indices values for computation of sustainable livelihood security index. Note: EEI = economic efficiency index; ESI = ecological security index; SEI = social equity index; SLSI = sustainable livelihood security index.

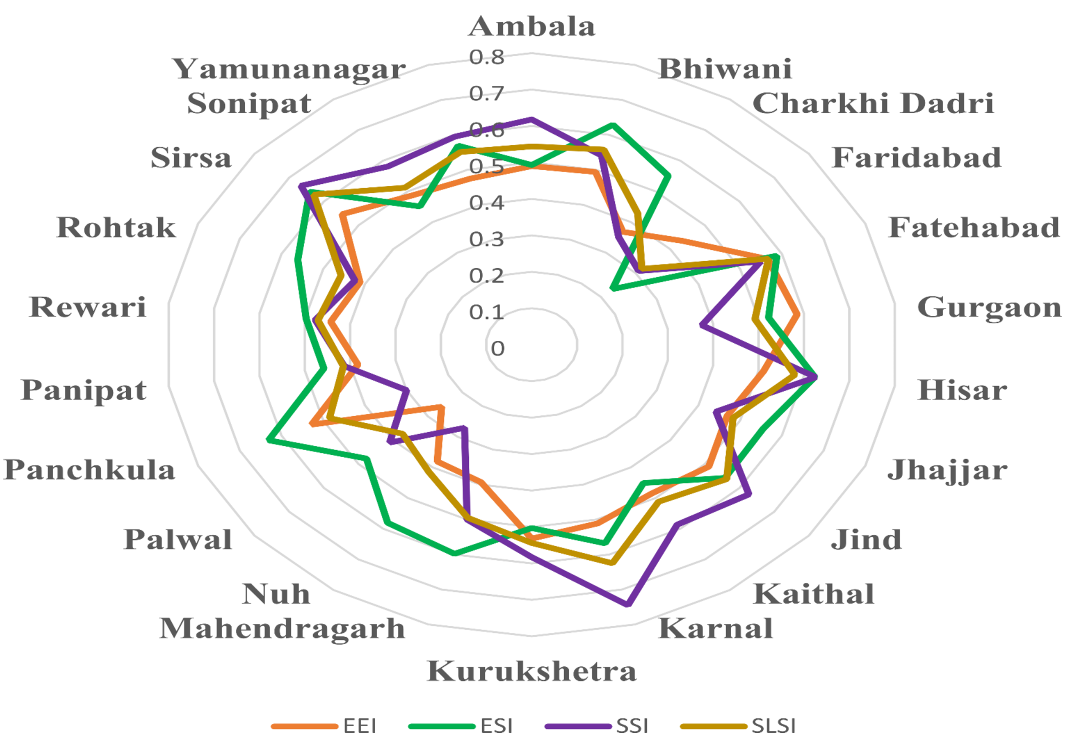

Fig. 2. District wise representation on various sustainable livelihood security indices(Note: EEI = economic efficiency index; ESI = ecological security index; SEI= social equity index; SLSI = sustainable livelihood security index).

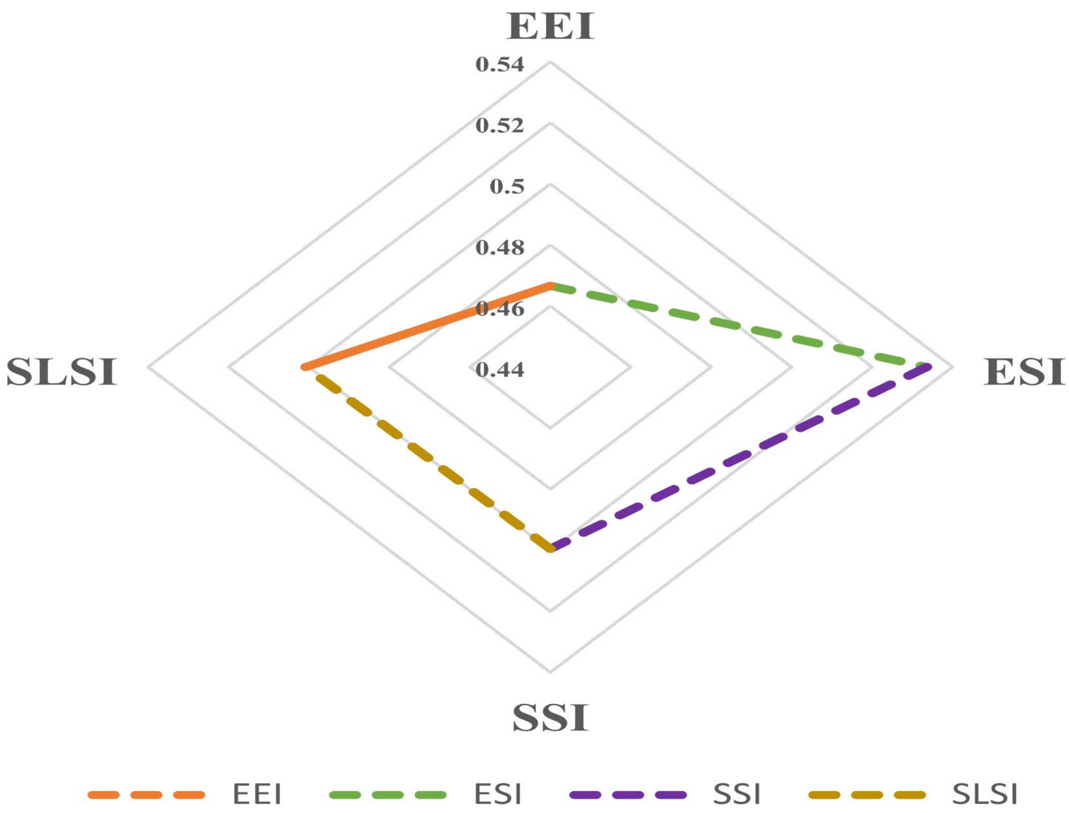

Fig. 3. Overall mean index values of sustainable livelihood security dimensions(Note: EEI = economic efficiency index; ESI = ecological security index; SEI = social equity index; SLSI = sustainable livelihood security index).

a evaluative tool. The empirical analysis of the Economic Efficiency Index (EEI), Ecological Security Index (ESI), Social Equity Index (SEI) and Sustainable Livelihood Security Index (SLSI) in Haryana revealed significant policy implications for promoting sustainable development across districts in the state of Haryana.

- *Targeted Agricultural Investments*: Districts with SLSI values below 0.4, indicating poor conditions for Sustainable Development Agriculture (SDA) that should be prioritized for high-level agricultural investments which includes allocating resources strategically to enhance agricultural productivity, promote sustainable practices and address specific challenges in the identified districts.
- *Strategic Focus on Afforestation and Livestock Development*: If the ESI values of a district are lower than the other two indices that emphasis should be placed on development projects related to afforestation, agro-forestry, cultivated area, and livestock development.
- *Equity-Enhancing Social Programs*: If SEI values of a district are lower than both ESI and EEI, priority should be given to equity-enhancing initiatives which includes investments in education, healthcare facilities, improved sanitation, rural infrastructure development (including road connectivity and electrification) and other social programs to address disparities and promote inclusive growth.
- *Sustainable Agricultural Systems*: To develop a sustainable agricultural system, there is a need for the appropriate utilization of local resources and effective environmental management which involves empowering farming communities by leveraging local knowledge, skills, cultural practices, and institutions.

Limitations
The study provides valuable insights into the agricultural sustainability of Haryana, it is subject to several kinds of limitations. Initially, the availability, completeness, and reliability of data have restricted due to the dependence on secondary data sources including government reports and district-level surveys. Differences in reporting standards and collection methodologies can also end up in inaccuracies or inconsistencies in these data sources. Furthermore, the results may have been influenced by the potential biases that are inherent in secondary data, such as regional disparities and variations in data quality across districts. Although the 28 sustainability indicators selected are exhaustive, they are predicated on assumptions regarding the most pertinent factors for agricultural sustainability, and it is possible that other significant indicators were disregarded. Also, because the study uses data from only one point in time, it cannot fully show how sustainability changes and develops over time. While Principal Component Analysis (PCA) is useful for reducing data complexity, it may miss some of the more complex, non-linear interactions between variables and assumes that relationships are linear, which could has affected how we interpret the principal components. Finally, the study's focus on Haryana limits the

District	EEI		ESI		SSI		SLSI	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Ambala	0.490	10	0.493	17	0.618	5	0.544	8
Bhiwani	0.494	9	0.629	3	0.541	11	0.558	6
Charkhi Dadri	0.368	21	0.551	13	0.351	19	0.428	18
Faridabad	0.435	16	0.233	22	0.309	20	0.318	22
Fatehabad	0.566	2	0.588	6	0.549	10	0.568	4
Gurgaon	0.585	1	0.522	14	0.375	18	0.492	13
Hisar	0.511	6	0.624	4	0.626	4	0.580	3
Jhajjar	0.469	14	0.555	12	0.442	14	0.483	15
Jind	0.511	8	0.558	11	0.627	3	0.563	5
Kaithal	0.485	12	0.451	20	0.587	7	0.512	11
Karnal	0.511	7	0.568	9	0.745	1	0.625	2
Kurukshetra	0.532	4	0.503	15	0.583	8	0.544	9
Mahendragarh	0.393	18	0.598	5	0.500	12	0.495	12
Nuh	0.381	20	0.581	7	0.271	22	0.415	20
Palwal	0.260	22	0.477	18	0.410	17	0.373	21
Panchkula	0.528	5	0.631	2	0.300	21	0.485	14
Panipat	0.383	19	0.458	19	0.413	16	0.415	19
Rewari	0.443	15	0.497	16	0.477	13	0.471	16
Rohtak	0.412	17	0.561	10	0.424	15	0.457	17
Sirsa	0.547	3	0.641	1	0.666	2	0.629	1
Sonipat	0.486	11	0.451	21	0.581	9	0.523	10
Yamunanagar	0.475	13	0.569	8	0.595	6	0.551	7

Table 7. District wise ranking of EEI, ESI, SSI and SLSI. Note: EEI = economic efficiency index; ESI = ecological security index; SEI = social equity index; SLSI = Sustainable livelihood security index.

generalizability of the findings to regions with different socio-economic and environmental conditions. These limitations should be kept in mind when interpreting the results. Future research could address these challenges to enable more comprehensive and robust assessments of sustainability in agricultural systems across diverse contexts.

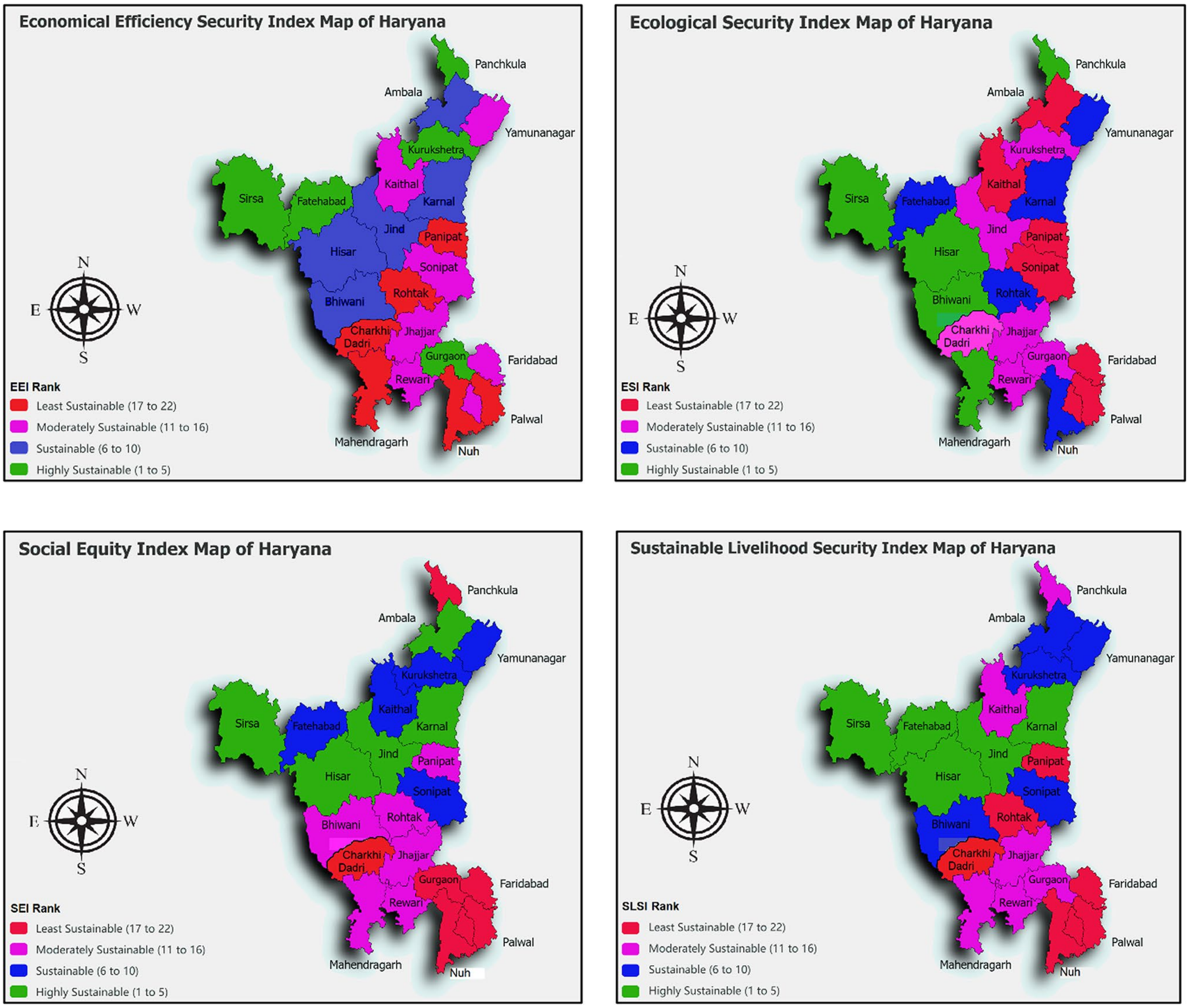

Fig. 4. EEI, ESI, SEI and SLSI maps of Haryana, India.Note: the map in this figure was created using the open-access, free online tool "Paintmaps" https://paintmaps.com/map-charts/246c/Haryana-map-chart which does not require any subscription and it is a free, online, interactive map chart generating tool.

Sl. no	Particulars	Less sustainable	Moderately sustainable	Sustainable	Highly sustainable
1	No. of districts	6	6	5	5
2	Total area (ha)	6,616,956 (26.10% of TGA)	5,930,854 (23.39% of TGA)	5,983,045 (23.60% TGA)	6,820,607 (26.90% of TGA)
3	Total population affected*	781,500 (17.68%)	980,000 (22.17%)	1,057,700 (23.92%)	1,602,000 (36.23%)

Table 8. Area and population under different degrees of SLSI in the state of Haryana. Note: Total population of state is 25, 351, 462*. TGA stands for total geographical area of the Haryana. The percentage to state TGA and total population are given in parentheses *As per human population census-2011 of the state.

Data availability

The dataset for the present study is available at public domain (https://esaharyana.gov.in/state-statistical-abstract-of-haryana/). The data sheets which were used for the analysis to obtain the results may be shared by the corresponding author on logical request.

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Author contributions

Author contributionData collection and analysis were conducted by G.J.T., S.B. and J.K.B. The manuscript has collectively written and authored byG.J.T., S.B. and J.K.B., D.K.B., N.B. and J.S.P. Finally, the complete research paper underwent examination and finalization by all authors.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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