Identifying entry points for agricultural transformation – a multidimensional analysis of farming systems in Maharashtra state of India

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Abstract:

This study employs a multidimensional framework analysing farming systems to identify entry points for transformation towards sustainability and profitability across seven districts of Maharashtra, India. Surveys of 204 households across diverse villages assess five sustainability domains: environmental, economic, productivity, social and human well-being. The analysis reveals mediocre sustainability achievements for all districts, with ample room for improvement. It also documents regional cropping patterns aligned with agro-climatic suitability and markets. Soybean and cotton were prevalent crops, while districts exhibit unique prioritizations like sugarcane and cereals. Considerable variability exists in net returns across locations and crops. Pulses and oilseeds show profit promise, but income security given its volatility remains imperative. The study estimates crop-specific impacts of yield, costs and prices on net returns using regression analysis. Results demonstrate that cotton profits are more sensitive to price incentives than yield gains, while soybean exhibits greater yield sensitivity. Balanced yield improvements and remunerative price environments can thus expand smallholder incomes. Though yield and market price are key drivers of farm economy but manging cost of production under certain situation is more important for enhancing sustainability. Overall, targeted interventions addressing sustainability gaps and risk management can enhance productivity, resilience, and rural livelihoods.

Keywords: Sustainability, Farm Income, Rural Development, India
JEL codes: Q01, Q12, Q18, O13, R11

1. Introduction:

Agriculture is the backbone of many developing countries, providing livelihoods for a majority of the population (World Bank, 2022). Transforming the traditional agricultural economy into a modern, resilient, and productive system is critical for sustainable development and food security across the developing world (Paroda & Joshi, 2019; Štreimikis & Baležentis, 2020). However, the majority of rural households in low and middle income countries continue to depend on small-scale, low income agriculture for their livelihoods (World Bank, 2022), while facing challenges like climate change, low productivity, market access barriers, and land constraints that trap them in poverty (Diao et al., 2016; FAO et al., 2021). Close to 80 percent of the extremely poor live in rural areas and rely on farming, indicating the centrality of agriculture in equitable growth strategies (FAO et al., 2021). Urgent policy interventions and innovations are needed to help smallholder farmers shift to sustainable intensification by increasing productivity, building resilience to shocks, and connecting to high-value markets (Pretty et al., 2018; Velten et al., 2015). This requires a multidimensional approach spanning technology adoption, access to inputs and credit, market linkages, and an enabling policy framework (Lee, 2005; Pretty, 2007). For instance, promoting climate-smart technologies like drought-tolerant seeds, micro-irrigation, and renewable energy applications can increase yields and incomes while lowering environmental impacts (Velten et al., 2015). Financial instruments like crop insurance, price stabilization funds, and flexible microcredit can help buffer farmers against weather and market volatility. Investments in transportation, storage, and food processing infrastructure are imperative for integrating small producers into commercial value chains domestically and globally (Pretty, 2007). Additionally, analytical insights into regional variations among farming systems are needed to tailor policy solutions to local contexts, agro-ecologies, and community needs. For example, mixed methods research employing detailed agricultural household surveys and qualitative techniques can compare challenges and opportunities across semi-arid, sub-humid and humid regions within a country (Lee, 2005).

Similarly, India's agricultural transformation remains uneven across states like Maharashtra which has diverse agro-ecological regions, namely Konkan, Western Maharashtra, Marathwada and Vidarbha. Climate variability significantly affects farming, especially in rainfed areas (Swami & Parthasarathy, 2021). Expanding irrigation has been a policy priority to enhance productivity (Mane, 2017). In Western Maharashtra, main crops have shown fluctuating productivity trends (Daundkar & Pokharkar, 2020). Despite agriculture's declining GDP share, its linkages with rural nonfarm income highlight an inclusive transformation pathway (Talule, 2015). Soybean cultivation is rising, with Maharashtra as India's second largest producer (Rathore et al., 2021). The state saw divergent crop performance during pre- and post-economic reform periods (Narwade, 2014). Persistent challenges in raising rural incomes indicate uneven progress (Sakharam et al., 2014). Diversifying rural livelihoods and managing vulnerabilities can improve well-being and transform rural economies, overcoming uneven distribution of production assets and poor governance (Kumar et al., 2015).

The new agricultural measures have enhanced production but bypassed the equity issue, leading to the emergence of a class of rich farmers dominating rural society. The objective is to create a market and growth-oriented rich farmer-led agriculture, with equality considered a myth constituting politics (Mohanty, 2001). An integrated farming systems approach enhances productivity, profitability and sustainability; adoption of allied enterprises increases net returns; under irrigated conditions, mixed farming with crossbred cows yielded the highest net profit (Meena et al., 2022). A study in Karnataka found a high proportion of old farmers with significant education levels, majority having big land holdings, and livestock, crops and services being key livelihood sources, with variations across taluks (Desai et al., 2012). Another study investigates the rise of family labor farms in India from structural shifts, as small multi-enterprise farms resemble East and Southeast Asian models, relying on long-term survey data and statistical analyses determining this transition (Djurfeldt & Sircar, 2016). Diversification towards high-value crops can enhance farmer welfare in some regions (Anuja et al., 2020). Studies suggest the high-value segment can benefit smallholders through labor intensity and higher returns than cereals. Additionally, crop diversification plays a crucial role in employment, income, poverty alleviation, and sustainability via efficient natural resource use (Singh, 2012). Overall, the studies highlight the complex and uneven nature of India's agricultural transformation. While progress has occurred through irrigation expansion, allied activities, and high-value crops, challenges persist regarding climate risks, regional disparities, rich farmer dominance, and rural income growth, requiring integrated policy approaches.

Against this backdrop, this study employs a multidimensional framework integrating technology adoption, market access, food security and environmental sustainability to assess agricultural transformation opportunities for Maharashtra’s farming households. The study employs a multidimensional framework assessing technology adoption, market linkages, food security and sustainability across Maharashtra's farming households for identifying tailored agricultural transformation opportunities.

2. Data and Methodology:

2.1. Location and sample selection:

This study was undertaken across seven demographically and geophysically diverse districts of Maharashtra, selected via extensive secondary data analysis, consultations with pertinent stakeholders, and preliminary site visits. The focus districts were Buldhana, Jalna, Latur, Nagpur, Nashik, Pune, and Solapur (Figure 1). Using a stratified sampling method, specific villages were selected across the districts to represent their distinct agricultural and rural characteristics (Figure 2). These specific locations were carefully selected across different districts to get a better understanding of how things are done in agriculture and rural life in various areas. In Buldhana district, Ubalkhed village in the Motala block was chosen. Masegaon village in Jalna's Ghansawangi block and Matephal village in Latur's Latur block were selected as well. Khursapur village in the Katol block of Nagpur district was selected for its orange orchards. Ghorwad village in Nashik's Sinner block offered insight into grape cultivation. For an advanced agricultural perspective, Chambali village in Pune’s Purandar block was picked. Finally, to represent an arid region, Bhend village in Solapur's Madha block was chosen. In total, 204 households across the seven selected villages were surveyed, with distribution across locations shown in Figure 3. This sampling aimed to provide diverse representation of the regions. The sampling methodology aimed not only to capture the diversity across districts but also to ensure a comprehensive understanding of the intricate agricultural systems and rural lifestyles prevalent in Maharashtra. By meticulously selecting villages that encapsulated the essence of their respective regions, this study endeavored to provide a nuanced and comprehensive analysis of the agricultural landscape and rural livelihoods across the surveyed areas.

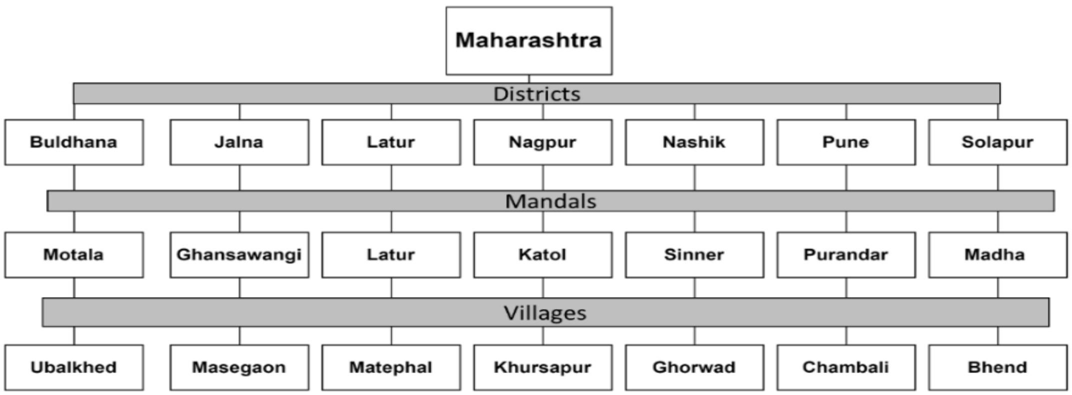

Figure 1: Flowchart of the study locations: state, districts, mandals and villages

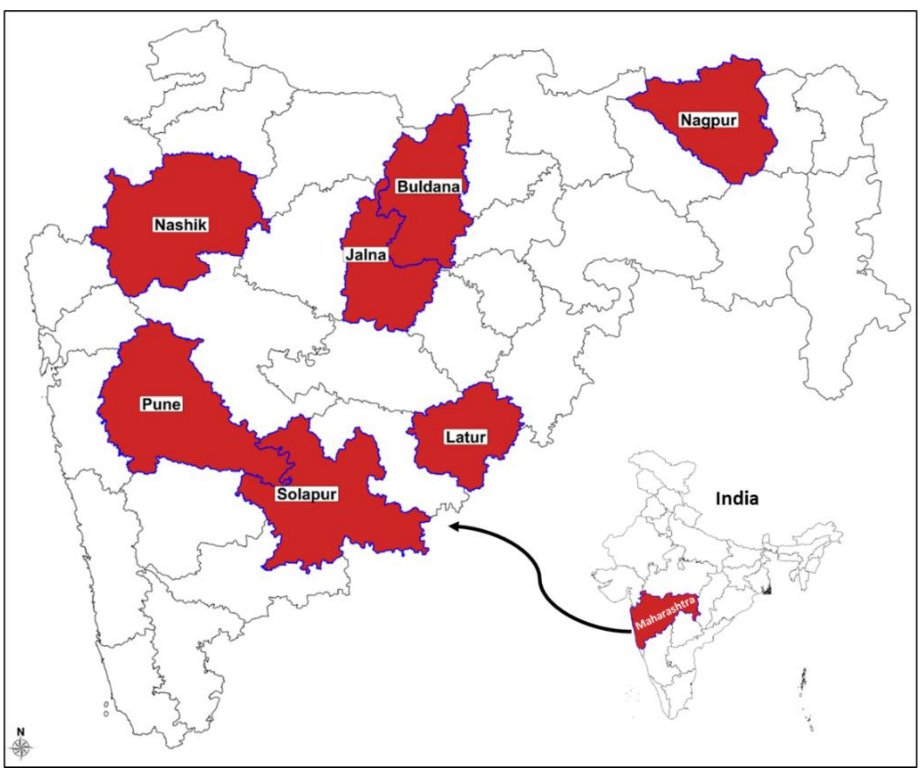

Figure 2: Location of the study districts

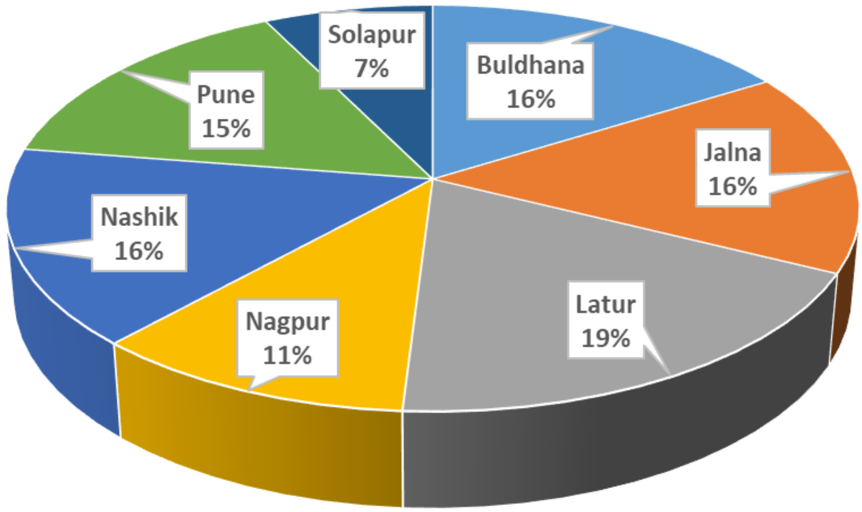

Figure 3: Location wise distribution of sample households

2.2. Methodology:

The study was conducted in two folds, firstly to understand the multidimensional sustainability status of the sample households and secondly to elucidate cropping patterns, returns from major crops, factors and determinants of households crop income considering major crops. The detailed methods used in this study are described below.

2.2.1. Estimating multidimensional sustainability indicators:

The Multidimensional Sustainability Assessment Tool parameterized and developed by ICRISAT, helps in evaluating the domain and themes specific sustainability of farming systems. This framework, characterized by five core domains—environmental, economic, productivity, social, and human well-being—emerges as an easily measurable and comparable instrument. Through extensive collaboration with stakeholders including farmers, researchers, and development actors, 124 measurable indicators were identified and streamlined across these domains (figure 4). This facilitated the creation of an aggregated index, reaching a maximum value of 100, signifying the level of sustainability and resilience at diverse scales. This tool simplifies the complex task of quantifying farming system sustainability by assigning stakeholder-assigned weights to the defined indicators measuring various domains. This adaptable and holistic tool serves as a useful guide in fostering sustainable practices and resilient farming systems in diverse agricultural landscapes.

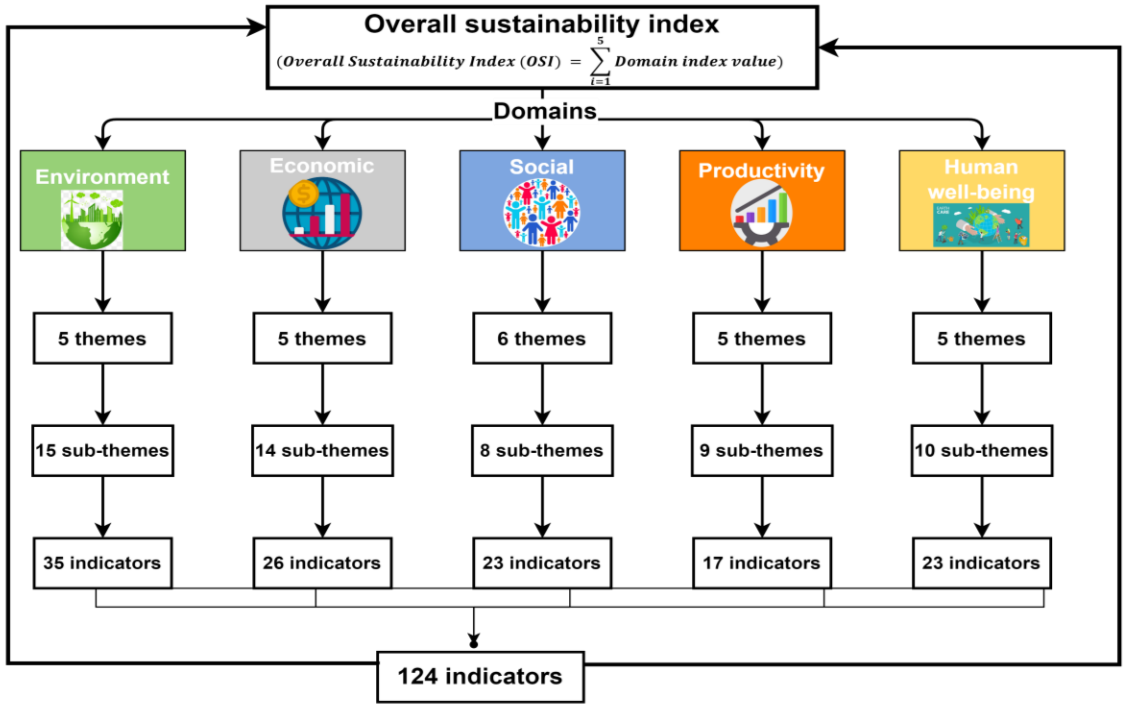

Figure 4: Flow-chart of multidimensional sustainability index: Journey from domains to indicators

2.2.2. Cropping pattern, crop income and its determinants

We conducted an analysis of household survey data to understand cropping patterns and crop income dynamics across districts. We documented the major field crops cultivated within each district based on the crop production data reported by sample households. This provided an overview of the predominant crops in each region.

Next, we estimated gross and net crop income for each household following standard methods described in agricultural economics literature. Specifically, gross crop income was calculated by multiplying crop yield by crop price, while net income subtracted out production costs like seeds, fertilizers, pesticides, labor, irrigation, and machinery rental. These calculations provided insights on the profitability of different crops. We then performed an ordinary least squares (OLS) regression analysis to assess the influence of three key determinants on net crop income per hectare: crop yield (kg/ha), crop price (INR/kg), and production costs (INR/ha). The regression model was specified as:

Crop net return (INR/ha) = $\beta_0 + \beta_1$Crop yield (kg/ha) + β_2Crop price (INR/kg) + β_3Production costs (INR/ha) + ε (1)

Where the β terms represent the estimated regression coefficients. This analysis aimed to quantify the marginal effects of changes in yield, price, and costs on per-hectare profitability.

For the regression, we focused on three major field crops - cotton, soybean, and wheat - which were widely cultivated across a large number of sample households. The household-level crop production data provided the basis for the yield, price, cost, and income variables used in the regression. Interpreting the results revealed which factors had the largest impact on net returns.

3. Results and discussion:

3.1. Understanding the multidimensional sustainability of the Farming Systems to identify leverage points:

3.1.1. Overall sustainability status at aggregate level and household level:

In this section, we have presented results of analysis of the multi-dimensional sustainability and resilience of 199 farming households across seven locations in India. We initially selected 204 households, but excluded five due to data anomalies. Sustainability was assessed across 5 domains, aggregated into an overall score (Equation 2) ranging from 0-100. This enables comparison of sustainability status between districts and households (Figure 5).

$$\boldsymbol{Overall\ Sustainability\ Index\ (OSI)} = \sum_{i=1}^{5} \boldsymbol{Domain\ index\ value} \qquad (2)$$

Overall, sustainability scores were low, with no district exceeding 50 out of 100. Buldhana, Pune, and Solapur scored the highest with 47, while Nagpur scored the lowest with 40. This variability highlights room for improvement. Individual household scores ranged from 30 to 58, mostly between 35 and 43, indicating consistently mediocre performance. However, 15% of households scored above 50, demonstrating the potential for broader enhancement by identifying and sharing their successful practices. Therefore, the analysis indicates that to raise sustainability, we must identify interventions tailored to specific gaps. Districts performing poorly, like lowest-scoring Nagpur with 40, require distinct initiatives addressing shortcomings. We can facilitate cross-district and cross-domain learning to propagate best practices from higher-scoring households and districts to provide templates for advancement. For example, top districts Buldhana, Pune and Solapur can serve as models. Comparing achievements across the five sustainability domains pinpoints where specific districts and households need improvement. Enabling policies and technical assistance should concentrate on lifting households' weakest domains.

Ultimately, detailed analysis enabling customized interventions was crucial for improving the sustainability and resilience of Indian farming systems. Best practices must be promoted from higher-performing districts and households to raise overall sustainability. Addressing lagging domains and districts is also critical for enabling robust food systems and farmer livelihoods over the long term. Proper targeting through domain and location-specific insights will lead to efficacious policies, technical assistance and knowledge sharing for impactful outcomes benefiting households and communities.

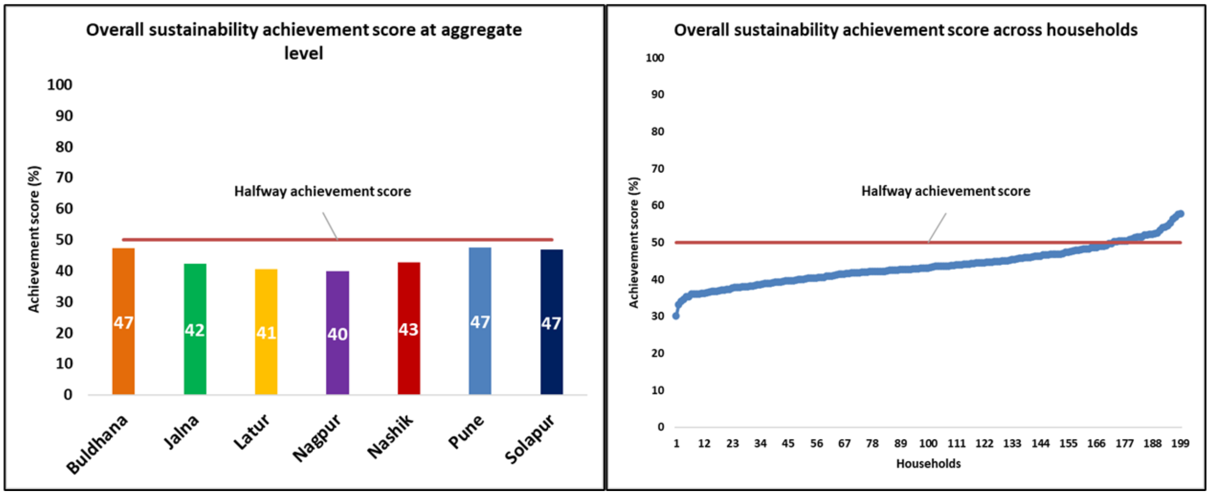

Figure 5: Overall farming systems sustainability achievement score at aggregate and household level across districts

3.1.2. Analyzing achievement of Environmental domain in aggregate as we as across household:

The assessment of environmental domain achievement scores was pivotal in evaluating status of environmental indicators, revealing diverse performances across districts and households, as depicted in figure 6. At the district level, an examination of scores highlights varying environmental performances. Pune exhibits the highest score of 58, followed by Solapur (54), Buldhana (52), Nashik (47), Nagpur (45), Jalna (46), and Latur (41). This disparity underscores the diverse environmental sustainability achievements across districts. Analyzing environmental scores at the household level illustrates a wide variation among farm haouseholds, ranging from 30 to 81. The majority of households cluster between 35 and 58. Notably, approximately 39% of households achieve scores of 50% or higher, indicating adoption of environmentally sustainable practices by the farmers. Some households exhibit notably higher scores, suggesting potential exemplary environmental practices.

While districts like Pune and Solapur lead in average scores, Nagpur and Latur trail behind. However, the distribution of scores at the household level shows high variation within each district, emphasizing the need for detailed evaluations to pinpoint factors contributing to higher or lower scores. Emphasizing the dissemination or promote learnings of successful environmental practices from higher-scoring households to lower-scoring ones can significantly improve overall environmental sustainability.

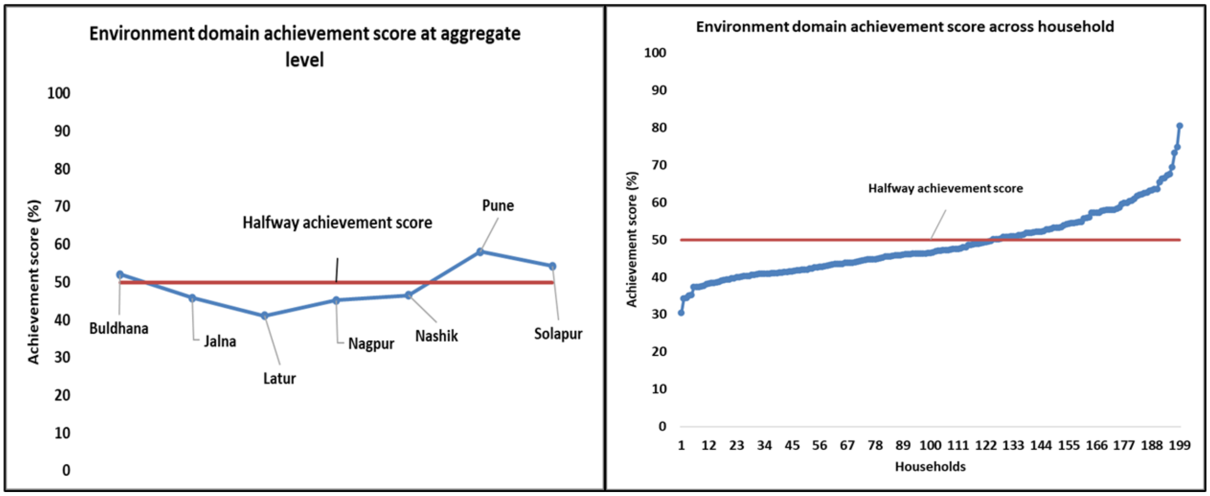

Figure 6: Environment domain achievement score (%) at aggregate and household level across districts

3.1.3. Analyzing achievement of Economic domain in aggregate as we as across household:

The Economic domain's achievement scores, examined at both district and household levels, revealed notable variations in economic sustainability performances (figure 7). When considering aggregate district scores, Pune displays the highest economic sustainability score at 45, followed by Buldhana (42), Nashik (36), Solapur (37), Jalna (34), Latur (35), and Nagpur (33). These divergent scores among districts illustrate diverse economic sustainability achievements across the surveyed areas.

Analysing household-level economic domain scores unveiled a wider range of achievements, spanning from 20 to 56. The majority of households cluster between 32 and 45. Remarkably, only 4% of households achieved scores of 50% or higher, indicating limited economic sustainability practices in these cases. The farm household falling below 35 or 40 need special attention. While Pune holds the highest average district score, Nagpur reports the lowest, emphasizing the disparity among districts. However, a more dispersed distribution of scores at the household level within each district highlights varying economic achievements. This dispersion emphasizes the need for a detailed evaluation at the household level to understand specific factors contributing to higher or lower scores. Insights from this comparative analysis stress the importance of tailored interventions at both district and household levels.

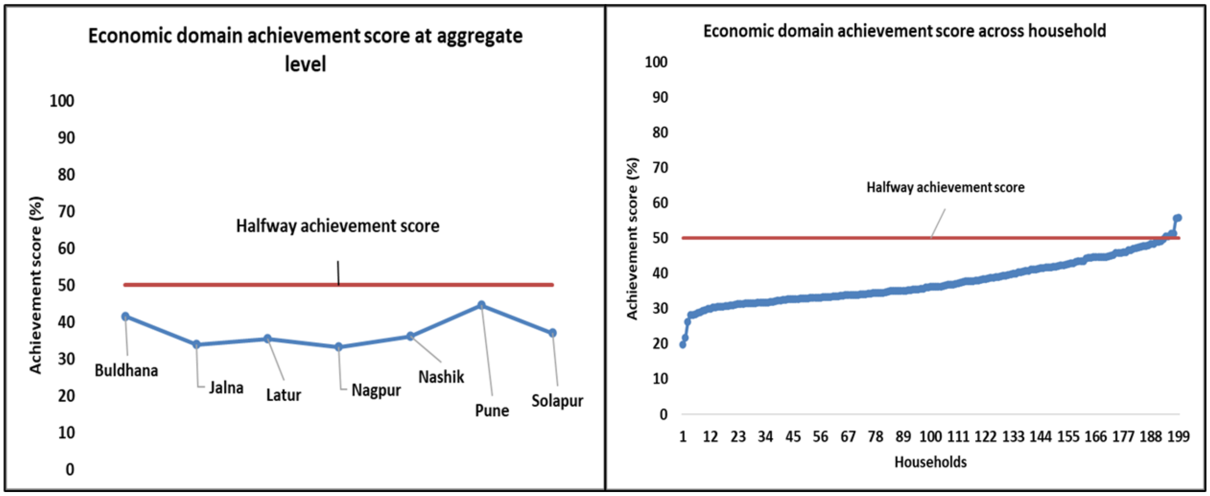

Figure 7: Economic domain achievement score (%) at aggregate and household level across districts

3.1.4. Analyzing achievement of social domain in aggregate as we as across household:

The Social domain achievement scores, both at the district and household levels, reveal considerable disparities in social sustainability performances (figure 8). The overall social score which includes gender dimension was quite low across districts. At the aggregate district level, Solapur emerges with the highest social sustainability score of 38, closely followed by Buldhana and Pune at 36. Latur, Nashik, Jalna, and Nagpur trail slightly behind with scores of 32-36. These varying scores among districts highlight diverse social sustainability achievements observed across the surveyed areas.

Upon analyzing the distribution of household-level social scores, a wide spectrum of achievements becomes evident. The scores range from as low as 19 to 55, with most households clustered between 29 and 34. Notably, only 3% of households achieved scores of 50% or higher, indicating poor social sustainability practices in the study regions. Comparatively, while Solapur and Pune hold the highest average district scores, Latur reports the lowest average score among districts. However, at the household level, a more dispersed distribution is visible, suggesting a diverse range of social achievements within each district. This dispersion emphasizes the need for a granular evaluation at the household level to discern specific factors contributing to higher or lower scores.

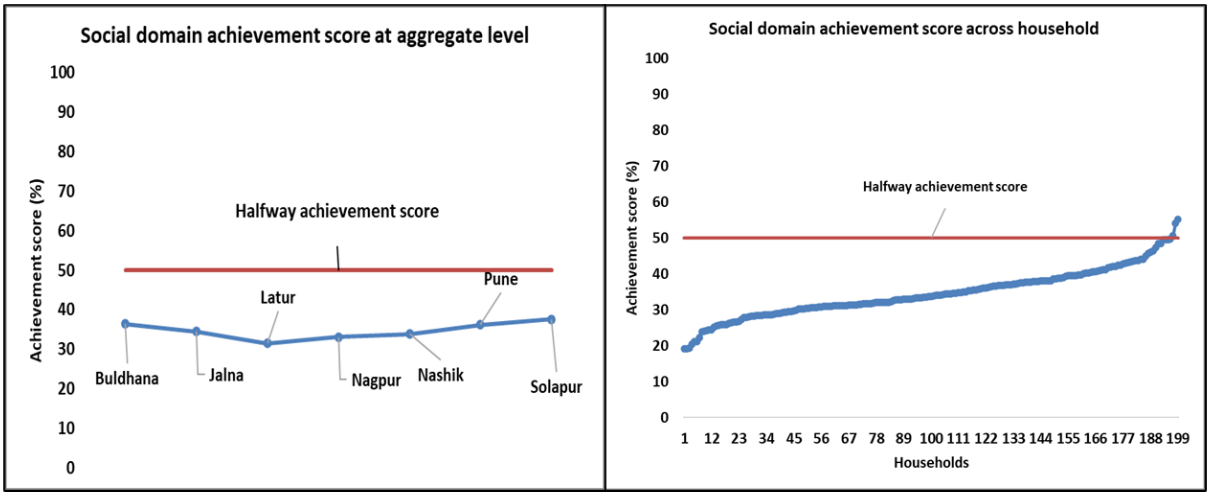

Figure 8: Social domain achievement score (%) at aggregate and household level across districts

3.1.5. Analyzing achievement of productivity domain in aggregate as we as across household:

The Productivity domain achievement scores at both the district and household levels provide diverse insights into farming systems' productivity performances and the results illustrated in figure 9. At the aggregate district level, Buldhana exhibits the highest productivity score of 38, followed by Jalna and Nashik at 35 and 32, respectively. Solapur and Latur stand close with scores of 33 and 32, while Nagpur and Pune report slightly lower scores at 26 and 28. The overall low score for productivity domain across districts is matter of concern.

Examining household-level productivity scores revealed a broad spectrum, ranging from 8 to 60, with most households clustered between 20 and 35, indicating lower performance levels. It shows that in certain farming systems the system's productivity is unviable. Surprisingly, only 3% of households achieved scores of 50% or higher, the lowest among all domains, signaling poor overall performance in this domain at the household level. However, a few households exhibit notably higher scores, suggesting exceptional productivity practices. Comparatively, while Buldhana holds the highest district average score, Nagpur reports the lowest among districts. However, at the household level, a more dispersed distribution is evident, showcasing a diverse range of productivity achievements within each district. Therefore, understanding the variability among districts and households allows for targeted strategies, aiming to elevate productivity levels across all segments. This data-driven approach is pivotal for refining strategies, promoting better practices, and ultimately elevating overall productivity across districts and households.

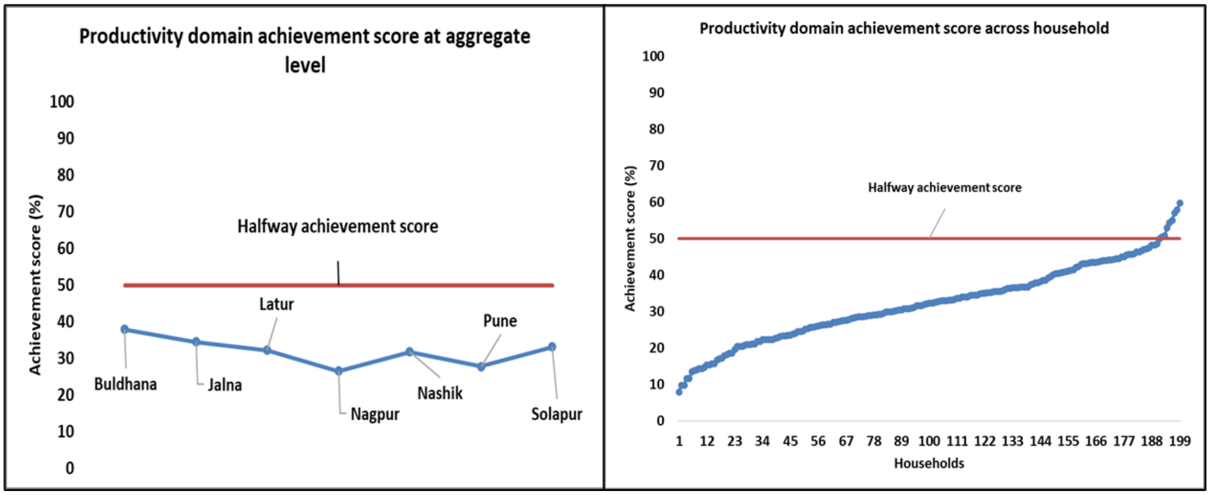

Figure 9: Productivity domain achievement score (%) at aggregate and household level across districts

3.1.6. Analyzing achievement of human well-being domain in aggregate as we as across household:

Comparing all five domains, human well-being domain performing best. At the aggregate district level, Solapur exhibits the highest Human Well-being score of 72, closely followed by Pune at 70. Buldhana, Nashik, Jalna, and Latur showcase relatively comparable scores ranging between 62 and 69. The better scores in this domain may be result of improved infrastructure and access to public services.

The distribution of Human Well-being scores at the household level showcases a diverse range from 45 to 87, with many households clustered between 55 and 81. Notably, almost all the households (99%) scored 50% or higher, indicating a considerable proportion of households focusing on aspects contributing to human well-being. Solapur has the highest district average, while Nagpur has the lowest among districts. However, at the household level, a broad spectrum of achievements is observed within each district, underscoring the importance of localized interventions. Furthermore, insights from this analysis emphasize the significance of understanding and fostering factors that contribute to higher Human Well-being scores. Encouraging practices from high-scoring households to lower-scoring ones and fostering knowledge exchange among districts can notably enhance overall human well-being. Also, understanding the variability among districts and households allows for targeted strategies, aiming to elevate human well-being levels uniformly. This data-driven approach is pivotal for refining strategies, promoting better practices, and ultimately elevating overall human well-being across districts and households (figure 10).

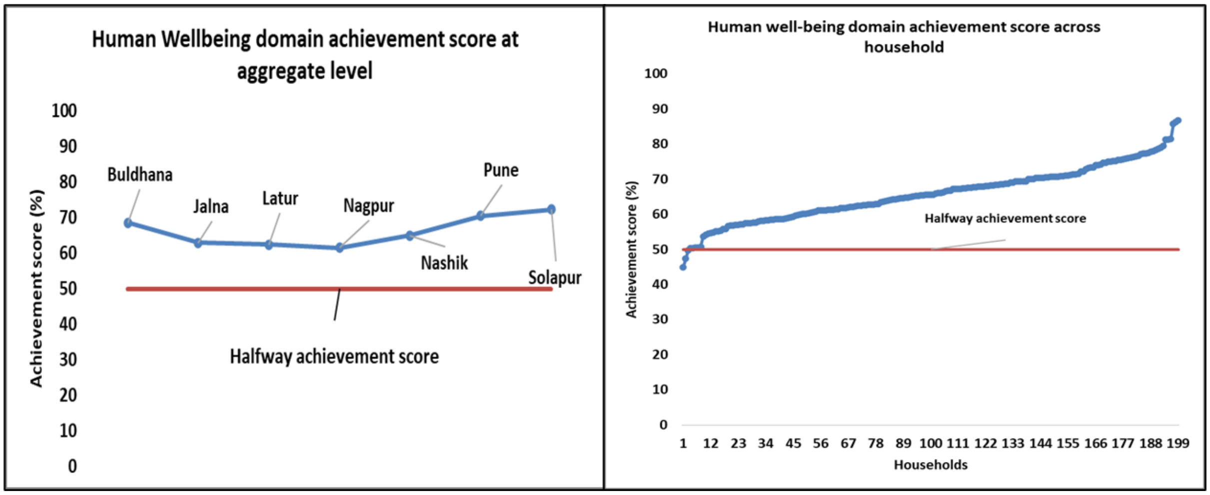

Figure 10: Human well-being domain achievement score (%) at aggregate and household level across districts

Finally, analyzing overall sustainability score and comparing domain wise achievement across locations and at household level it can be mentioned that the study across sustainability domains highlighted distinctive trends. Pune emerged as a consistent top performer, excelling in environmental and economic sustainability, while Solapur and Buldhana showcased strong social sustainability. At the household level, disparities were evident, indicating varied adherence to sustainable practices. The key insight lies in the vast range of scores, showcasing the diverse levels of sustainability across districts and households.
Overall, the findings highlight significant disparities across districts in each sustainability domain. Pune consistently emerges as a leading district in Environmental, Economic, and Human Well-being domains, indicating stronger overall sustainability. Nagpur consistently reflects lower achievements across multiple domains, signaling the need for focused interventions. Solapur and Buldhana also demonstrate strong performances in specific domains, emphasizing the importance of targeted strategies and knowledge sharing to enhance sustainability uniformly across all domains and districts.

3.2. Cropping pattern, crop income and crop suitability analysis:

3.2.1. Cropping pattern:

The cropping patterns across the seven studied districts of Maharashtra state of India indicate regional priorities aligned with agroclimatic suitability as well as market forces. The major field crops represent the dominant agricultural commodities by land area dedication in each district (table 1). Meanwhile, the minor crops signify supplemental productions of local importance. Soybean constitutes a prevalent major crop across multiple districts, potentially reflecting its reasonable input costs, drought tolerance, global market demand and high oil content. Buldhana, Jalna and Nashik districts cultivate soybean at scale alongside two other primary crops suiting the regional context. Cotton also claims extensive land area as a chief crop in three districts, indicative of textile industry appetite and cotton's relative insensitivity to precipitation fluctuations. Beyond soybean and cotton commonalities, unique major crop selections distinguish the cropping profiles of each district. For example, Solapur and Latur prioritize sugarcane and soybeans respectively based on favorable growing conditions and irrigation infrastructure investments. The prominence of wheat in Nashik, Nagpur and Pune, along with paddy in Nashik, indicates aims to diversify crops in order to meet domestic evolving food consumption needs; additionally, the cultivation of these cereals takes advantage of available water resources to produce staple commodity crops with reliable market demand. Groundnut prevalence in Pune and Solapur is logical given the legume’s limited water needs once established and rising demand for plant-based oils and proteins. Meanwhile chickpea persists as a low-input cash crop across five districts, enabling crop rotations to preserve soil fertility. The persistence of coarse cereal crops like sorghum and pearl millet for Pune and Solapur suggests dual household consumption and fodder purposes.

The inclusion of minor crops provides additional nuances regarding supplemental food and income sources for farmers facing climate uncertainties and fluctuating markets. For example, small-scale production of pulses and oilseeds beyond soybean contributes to agricultural biodiversity and nutritional security. Although less land extensive, fruits and vegetables like chilies constitute high-value cash crops. Therefore, the cropping patterns presented highlight regional dynamics shaped by agroecology, water availability, crop suitability, changing food habits, industrial demands, global commodity prices and climatic disruptions. Prioritization of major commercial crops optimizes profits, while minor crops support nutritional diversity and climate resilience. Analysis of adjustments in dominant crops over successive decades could reveal adaptation pathways for enhanced and sustainable agricultural production.

Table 1: Cropping pattern in the study locations: major and minor field crops by districts

Districts	**Major field crops**	**Minor field crops**
Buldhana	Chickpea, Cotton, Soybean	Chilies, Pigeon pea, Maize, Wheat
Jalna	Chickpea, Cotton, Pigeon pea, Soybean	Chilies, Green gram, Pearl millet, Sorghum, Sugarcane, Wheat
Latur	Soybean, Sugarcane	Pigeon pea
Nagpur	Cotton, Soybean, Wheat	Groundnut, Pigeon pea
Nashik	Paddy, Soybean, Wheat	Chickpea, Pearl millet, Maize
Pune	Groundnut, Sorghum, Wheat	Chickpea, Paddy, Sugarcane, Maize
Solapur	Black gram, Sugarcane, Maize	Chickpea, Groundnut, Pearl millet, Pigeon pea

3.2.2. Crops net returns at aggregate level and household level:

The net returns per hectare from major field crops in the seven studied districts reveal economic insights to guide sustainable agricultural decisions (Table 2). Considerable variability exists across locations and crops—but clear high-performers emerge.

Starting with pulses, chickpea proves highly profitable in Buldhana (INR 94,759/ha) and Jalna (INR 142,636/ha) while pigeon pea earns INR 53,210/ha in Jalna. The legumes likely benefit from global protein demand. However, cotton leads as Buldhana's top earner (INR 59,556/ha), mirroring the crop's dominance for Nagpur (INR 60,200/ha), again reflecting industrial markets. Noticeably, soybean constitutes the primary income source for multiple districts as a versatile oilseed and rotational crop, from INR 43,092/ha in Nagpur up to INR 98,199/ha in Jalna. Beyond widespread oilseed-cotton combinations, locations exhibit unique specializations like sugarcane for Latur (INR 254,563/ha) and Solapur (INR 294,018/ha), enabled by irrigation infrastructure suitability. Cereal crops also retain relevance, with wheat commanding INR 29,938-53,688/ha in Nashik, Nagpur and Pune amid evolving food habits. Rice similarly utilizes Nashik's water availability for substantial paddy returns (INR 69,200/ha). Additionally, coarse grains like sorghum enable crop diversification in Pune (INR 1,391/ha), while Solapur's black gram (INR 77,395/ha) and maize (INR 31,991/ha) productions reflect regional adaptation. But sustainability requires assessing economic risks: six major crops exhibit high variability in net returns per hectare (CV 45-126%). Chickpea ranges from INR 14,332 up to 223,543; cotton from an alarming INR -55,252 loss to INR 200,250 profits. Sugarcane (INR 78,182-528,629) and wheat (INR -62,599 to 155,982) also fluctuated markedly. This spread of crop-wise returns helps households and policymakers identify highly performing farmers as models and target lagging growers for intervention to promote sustainable agricultural systems (Figure 11).

In summary, major crops correspond to district-level strengths but balancing income security amid variability is key. While pulses and oilseeds show promise for profits, coupling these with cereals and industrial crops can mitigate volatility. Insights into economic landscapes and risks for different crops can thus guide regional efforts to match suitability with profitability for sustainable Indian agriculture. Therefore, in this respect it is necessary to understand how three major factors namely, yield, cost and price of a specific crops affect net returns of that particular crop across households and here we focused only on three major field crops - cotton, soybean, and wheat - which were widely cultivated across a large number of sample households.

Table 2: Study location wise average net returns from various major field crops (INR/Ha)

Districts	**Major crops with net return**
Buldhana	Chickpea (94759), Cotton (59556), Soybean (85546)
Jalna	Chickpea (142636), Cotton (22760), Pigeon pea (53210), Soybean (98199)
Latur	Soybean (58927), Sugarcane (254563)
Nagpur	Cotton (60200), Soybean (43092), Wheat (22733)

Nashik	Paddy (69200), Soybean (91268), Wheat (53688)
Pune	Groundnut (46517), Sorghum (1391), Wheat (29938)
Solapur	Black gram (77395), Sugarcane (294018), Maize (31991)

Note: values in the parenthesis are net returns (INR/ha) of the corresponding crop

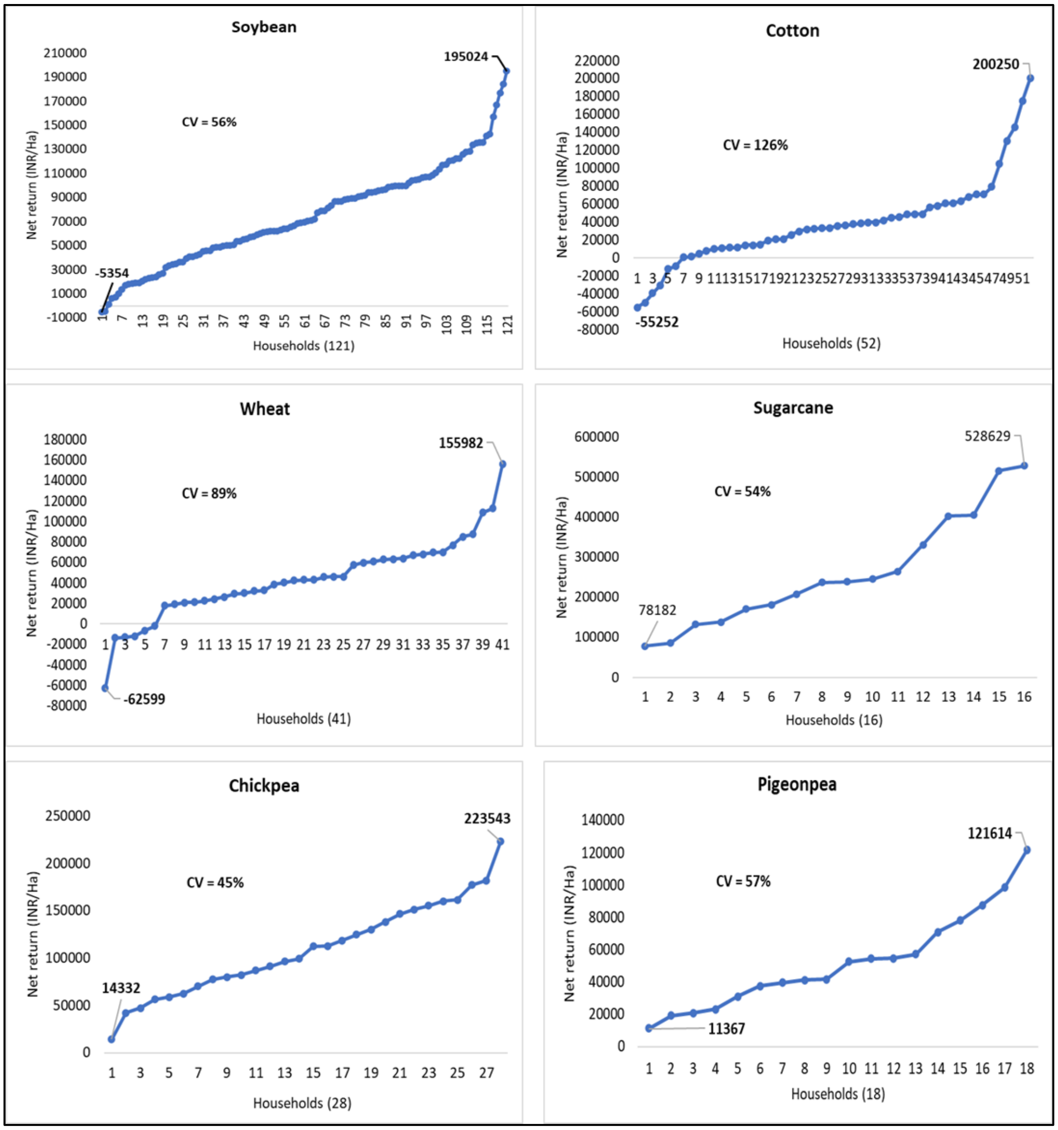

Figure 11: Net returns from various crops at household level (INR/ha)

3.2.3. Factors affecting crop specific net return across households

This section analyzes net returns from three major field crops - cotton, soybean and wheat - across sampled households. The goal is to understand variability in profitability across households for the same crops. The households are arranged in ascending order of net returns for visualization (figure 12). Soybean provides the highest average returns per hectare at INR 89,264, followed by cotton at INR 47,350. Wheat has relatively lower average returns per hectare at INR 20,288. This indicates soybean and cotton are more profitable crops in this region compared to wheat. There is high variability of net returns across households for the same crops. This highlights differences in soil quality, irrigation access, input costs and other locational factors. For example, soybean net returns range from as high as INR 1,95,023 per hectare to as low as negative INR 5,354 per hectare. In terms of risk and downside, soybean and cotton show higher volatility and losses among households. Wheat net returns are more consistently positive across households. The analysis also reveals high volatility in cost of cultivation, crop yields and market prices for all three crops. Some households have higher yields but lower net returns due to high production costs or lower market prices. The opposite also holds true - lower yields but higher profits for some households based on lower costs and/or premium prices. In summary, soybean and cotton are the most remunerative field crops amongst the sampled households in this region. The granular household-level data provides rich insights into relative profitability, risks and income variability across the major field crops. Therefore, the absolute impacts of these three covariate on crop specific net return is important and it has been evaluate below in details through a regression analysis method.

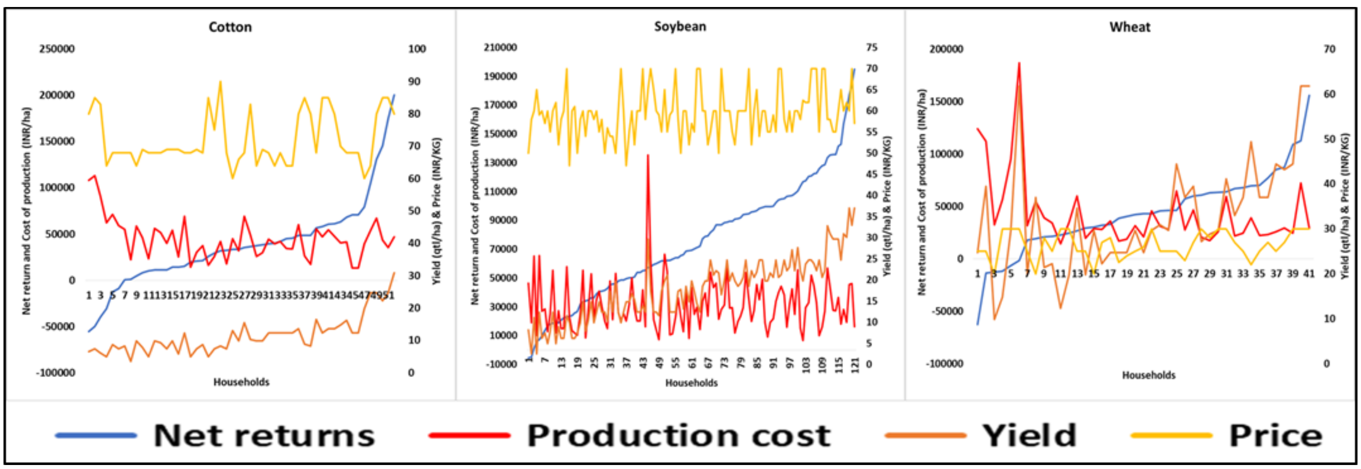

Figure 12: Return, cost, yield and price of three major field crops across households

The regression results in Table 3 estimate crop-specific impacts of yield, production cost and selling price on net returns for three major crops in India - cotton, wheat and soybean. The positive and statistically significant (at 1% level) coefficients on crop yield indicate that a unit increase in yield (Kg/Ha) leads to an increase in net return for cotton, wheat and soybean, ceteris paribus. This underscores the importance of yield-enhancing technologies and practices to improve farm profits. The negative and significant coefficients on production cost (INR/Ha) imply that a unit rise in costs decreases net return by almost a rupee for all three crops, highlighting the need for cost-saving innovations to expand margins. The positive and significant coefficients on selling price (INR/Kg) suggest that a unit increase in market price boosts net returns substantially for cotton, wheat and soybean. This signals the role of remunerative crop prices in raising smallholder incomes. The relative magnitudes of the crop yield, cost and price coefficients vary, indicating differential sensitivities. For cotton, selling price elasticity dominates, while yield elasticity leads for soybean. For wheat, price and yield effects are comparable. The results demonstrate that cotton cultivation is more responsive to output price incentives than yield gains for higher profitability. Soybean farming is influenced more by productivity increases relative to price changes. Wheat net returns exhibit sensitivity to both yield improvements as well as price rises.

Overall, the regression analysis provides useful crop-specific insights to guide policy interventions for raising smallholder profitability. While yield growth through improved technologies remains imperative, creating remunerative price environments through market linkages and value chains is equally important. A combination of productivity enhancement and price support policies tailored to local crop environments can effectively expand the net returns of smallholder farmers.

Table 3: Crop specific impacts of yield, cost and price on net return

Coefficients	Cotton	Wheat	Soybean
Crop yield (Kg/Ha)	75.48***	27.46***	59.18***
Production cost (INR/Ha)	-1.04***	-0.98***	-0.97***
Crop selling price (Kg/INR)	1249.24***	3106.20***	1722.67***
Constant	-91703.79***	-85744.57***	-102682.50***

Note: *** indicates coefficients are statistically significant at 1% level

4. Conclusions and implications:

This multidimensional assessment of agricultural sustainability across seven districts of Maharashtra provides useful insights to guide targeted interventions for enhancing the resilience and profitability of regional farming systems. Overall, sustainability scores were mediocre across districts and households, with ample room for improvement. Achievements were weakest in the productivity domain, indicating profitability challenges facing farmers. Environmental and economic sustainability also require advancement. Meanwhile social sustainability and human well-being fared relatively better. Moreover, huge variation in sustainability scores across households would be helpful in designing need-based interventions.

Analysis of cropping patterns revealed alignments with agro-climatic suitability and markets. Soybean and cotton are prevalent across districts as versatile oilseeds, while pulses add nitrogen and profits. Sugarcane thrives under irrigation in suitable districts. Cereals meet evolving dietary needs amidst water availability. Yet high variability in net returns across households and crops highlights income risks facing farmers. This granular analysis can suggest different strategies for the farmers in loss or have very low net returns. Lessons can be learned from the farmers achieving high net returns. Soybean and cotton were quite remunerative but exhibited volatility. The crop-specific regression analysis demonstrated that net returns are significantly influenced by yields, costs and output prices. Cotton incomes are more sensitive to price incentives than productivity gains. Soybean exhibits greater yield sensitivity relative to prices. Wheat is markedly impacted by both higher yields and prices.

These insights on regional agricultural systems have key implications for policymakers aiming to enhance sustainability, resilience and farmer livelihoods and encouraged to promote knowledge exchange and peer learning networks for propagating sustainable agronomic practices from high-performing districts and households to lagging areas. For example, Pune's successes can inform initiatives in lower-scoring Nagpur across multiple sustainability domains. Advance productivity through technologies tailored to regional cropping patterns and water availability. For instance, micro-irrigation and drought-tolerant varieties can stabilize yields. Create market linkages, value chains and infrastructure to support crop diversification towards high-value commodities. This allows farmers to capitalize on rising demand for horticulture, dairy and poultry. Offer financial instruments like insurance, price stabilization and flexible credit to help farmers manage income variability and risks from climate disruptions and volatile markets. Recognize regional and household specific heterogeneity in farming systems and priorities. Customized interventions aligned with agro-ecological strengths can sustainably raise productivity, farmer incomes and multi-dimensional sustainability.

In summary, an inclusive, multi-pronged approach towards agricultural development can enable prosperous and sustainable farming systems. A multi-dimensional perspective and data driven designing of farm and food systems strategies is critical transformation towards sustainability and profitability. Integrating marginalized voices in policy dialogue and decoupling farmer welfare from agricultural growth are pivotal for lasting, broad-based rural transformation. Also, a nuanced systems understanding of the multidimensional sustainability gaps, risks and opportunities facing India's agricultural households can facilitate targeted advancement pathways. Location-specific solutions spanning technology, markets, climate resilience harnessing agro-ecology and social support are key to overcoming barriers and equitably transforming regional farming systems. Integrated analytical approaches illuminate evidence-based transformations towards sustainable intensification.

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