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The Impact of Agroecological Zones on Sustainable Agriculture: A Case Study of Pakistan

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ABSTRACT

Objective: This paper's objective is to estimate the Sustainable Agriculture Index (SAI) to quantify sustainable agriculture through net revenue per hectare of each crop. It examines how economic, social, and environmental indicators are interrelated with this SAI index. Another objective is to determine the most efficient crop under agroecological zones to obtain sustainable agriculture.

Research Gap: Few researchers have examined sustainable agriculture adopting economic, social, and environmental indicators in 10 agroecological zones, distributed across districts in Pakistan.

Design/Methodology/Approach: The study will gauge SAI and will use the LSDV model to estimate the association between SAI and economic, social, and environmental indicators across 18 districts of three provinces, Khyber Pakhtunkhwa, Punjab, and Sindh.

The Main Findings: Results find wheat crop is somewhat sustainable to produce in Pakistan's districts but some important social variables like Tapwater, and BHUBeds are insignificant with the wheat SAI index. Similarly, rice, cotton, sugarcane, and jawar crops are not sustainable to grow in any district.

Theoretical / Practical Implications of the Findings: The farmers should adapt to climate change and use organic manure, green manure, mulching, and cropping rotation. Flood and drought water-resistant seeds and enhanced water conservation and storage techniques are some of the good techniques to adopt in agroecological zones for sustainable farming.

Originality/Value: The research paper is based on the author's own original research and contributes towards policy choice in the agriculture sector and favours small farmers to support new farming with innovation and new technology.

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1. Introduction

Sustainable agriculture covers efficient, environmental, and ecological sound farming that produces safe food and fibre for current and future generations. It promotes soil conservation, waste management, pollution control, clean water, biodiversity, supports rural community quality of life and farmers' income, and integrates economic, social, and environment indicators (Dumanski et al., 1998).

Sustainability promotes higher cropping Intensity, effective application of fertilisers and pesticides, adoption of organic methods, crop rotation, mixed farming, livestock management, adequate rainfall, access to groundwater, and enhancement of forest areas (Guha et al., 2018; Sajjad & Nasreen, 2016; S. Singh & Nayak, 2020a; Sundar Pani & Mishra, 2022). It is essential to have access to clean water, primary health services, education of farmers, cultivation awareness, and ownership of agricultural land in rural areas in order to achieve fair distribution of ownership and resources (Sajjad & Nasreen, 2016).

Climate change has impacted 58 percent of agricultural land out of 94 percent and raised problems of inadequate irrigation water and extreme temperatures in South Asia. With the production of agricultural produce, fertiliser application, and manure application, coupled with crop residue, it enhances methane gas and nitrous oxide. It has impacted on the initial and growing interval of crops, which mature crops early and has declined the crop-maturing cycle. The crop biomass residue, approximately 1,02,585.75 KT can generate electricity almost 9231.60 MW. The seed germination growth was also disturbed for wheat and rice crops because of rising temperatures (Akter et al., 2024; Pampana et al., 2022).

South Asia is more prone to rainfed and climate change has increased the vulnerability of these areas and declined crop productivity and protein content (Pampana et al., 2022; Rasul, 2021). The subsidy of fertiliser, free water, energy prices, pesticides, herbicides, support prices for water, and energy-intensive crops by the South Asian government increase agriculture output, but it also degrades the environment and damages the ecosystem, and raises rural community health issues (Rasul, 2021).To boost land productivity, Srilanka employs climate resilience measures such as rainwater harvesting, shared farming to manage water shortages, agrobiodiversity through mixed cropping, agroforestry, and crop production using seed-resistant cultivars (Ginigaddara & Kodithuwakku, 2024). The electricity reliability and reduction in electricity cost also boost farmers' productivity and generate employment (Ugembe et al., 2023).

In Pakistan, land fertility faces issues such as moisture stress, soil erosion and deterioration and crusting, nitrogen exhaustion, low nutrient use efficiency, and rising weed populations. Farmers in hilly regions struggle to address these issues scientifically, resulting in unsustainable yields (Baig et al., 2013). These farmers such as in Dera Ghazi Khan, irrigate the land with hilly rivers and climate change has increased river flow more than expected and together with the monsoon, raised floods (Habib et al., 2022; Qaisrani et al., 2018). The changing rainfall pattern has made it difficult to cultivate land for small growers and these growers use tubewells on rent to source water, but this increases their cost of production coupled with enhanced waterlogging and salinity problems(Nadeem et al., 2023).

The ecology of the land deteriorates due to poor waste management (WM), such as the burning of residue, which reduces organic nutrients and land fertility. The organic matter also lessens with the use of powerful tractors and machinery for levelling, threshing, and removing land residue (Akter et al., 2024; Hashim et al., 2022). Farmers must adjust to changes in the climate, and its exposure may be evaluated to prepare and effectively tackle it. Farmers who adopt livestock with cutting-edge technology to manage climate change have narrow land to breed livestock, where 75 percent of cattle have access to food. Low output efficiency is risking livestock farming, and it declines in milk and meat production. Cattle mortality is also high, resulting in stillbirths, inadequate reproduction of animals, and fertility(Usman et al., 2023).

Farming in agroecological zones is one of the better options in which the cropping pattern prefers local climatic conditions to global climatic change. The benefits of agroecological zones over conventional farming are that conventional farming involve different cultivating practices due to water scarcity or low amounts of water, and changing rainfall increases long-term drought spells (Mahmood et al., 2021). The agroecological zones use multiple cropping patterns with compost and crop mulching by using crop residue to enrich soil nutrients and soil productivity (Hashim et al., 2022). The season has shortened in agroecological zones, and farmers in South Asia are changing sowing dates. This depends on the condition of the zone’s specific needs and environment. The heat stress in plain areas results in early maturity, which leads to a loss of crop yield. At higher altitudes, the early sowing of crop in summer can result in a good yield because of the rising temperature in this season (Shah et al., 2021a).The wheat crop receives positive changes in temperature in all agroecological zones during sowing time and negative changes in harvesting time. The rice crop in Northern Irrigated Plain, Northern Dry Mountain, and Sandy Desert Region have positive changes in temperature, and are beneficial for the crop, whereas these zones face negative changes in rainfall for the rice crop (Abdullah et al., 2022). Climate adaptation can be beneficial for farmers by buying modern technology like drip irrigation, sprinklers, or changing growing dates, water-resistant and drought seed, efficient fertiliser, and soil protection methods. But financial constraints are the main hurdle for small farmers to adapt climate change(Abid et al., 2016).

In Pakistan, the Food and Agriculture Organisation (FAO) of the United Nations (UN) has divided Pakistan's agricultural land into ten zones based on climate, geography, agricultural practices, and plenty of water as shown in Table 1 (A. Ahmad et al., 2019).

The objective of this paper is to quantify sustainable agriculture through net revenue per hectare of each crop by making the Sustainable Agriculture Index (SAI). The second objective is to examine how economic, social, and environmental indicators are interrelated with this SAI index. The third objective is what most efficient crop under agroecological zones to obtain sustainable agriculture. Few researchers have tried to examine sustainable agriculture by adopting economic, social, and environment indicators in 10 agroecological zones, distributed across districts of Pakistan. The study will employ the LSDV model across 18 districts of three provinces, Khyber Pakhtunkhwa, Punjab, and Sindh to find out the SAI under agroecological zones to conclude that farmers can increase better productivity with sustainable quality of the environment. The papers will be as follows: Section II elaborates a review of the literature; Section III explains the methodology; Section IV elaborates results; and Section V explains the discussion and conclusion.

2. Literature Review

Among the sustainable agriculture indicators, social indicators negatively impact on environment such as low education, and illiteracy to write and read, and make it difficult to access information by extension departments. Pesticides and herbicides impact on humans and these chemicals also increase pests on crops because of reliance on one crop (Bagheri, 2010). Climate change also increases pests, diseases, and water shortage and it decreases crop yield (Alhassan et al., 2019).

Soil degradation and soil management are normal problems under monoculture practice (Blackmore et al., 2021). Another cause is water scarcity and inadequate soil nutrients, and this leads to cutting vegetation, managing soil inappropriately, and increasing poverty (Tesfahunegn, 2017). In addition, land productivity and price distortion had a key negative impact in 28 developing countries from 1971 to 1980, though increasing agriculture output and food production was positively associated with variation in arable and permanent land. Price variation impacted on both enlargement crop output and agriculture, but land erosion causes the decline of food production during the short-run and long-run in underdeveloped economies (Zhao et al., 1991).

In Pakistan, water scarcity in rice-growing regions, with increased floods and droughts, is growing insects, has degraded soil, and reduced yield. Climate change has increased temperatures with declining rainfall and floods have displaced rural inhabitants from their areas, reducing crop yield (N. A. Khan et al., 2021; Qazlbash et al., 2021; Shahid et al., 2021). The groundwater fulfills 45 percent needs of crops, and its water tables are decreasing and contaminating it (Hassan & Hassan, 2017). Pakistan in Punjab is utilising more water than required and by incorporating Gravity Recovery and Climate Experiment (GRACE) total water storage anomalies (TWSA) and landset 8 data support the efficiency of an effective Irrigation Advisory System and can save 81 percent of groundwater(Nadeem et al., 2023).

The adaptation techniques farmers are taking such as drip irrigation, and sprinkles, changing the growing dates of crops, changing seed variety, and cropping patterns, managing fertiliser applications, soil conservation methods, employing organic manure, and buying low water-intensive crop categories. However, they encounter obstacles to adapt to this because of rising costs, and inadequate technical knowledge to apply the adaptation approach. Growers' educational background, off-farm income, water resource possession, and institutional variables including having accessibility to knowledge about the climate, agricultural counsel, and financing options all play a role in adaptation. Females and illiterate growers are more inclined towards climate adaptation than male and educated farmers (Alhassan et al., 2019; Khan et al., 2021; Qazlbash et al., 2021; Shahid et al., 2021). Extension services further influence adaptation strategy and information like education on wheat farming for climate-resilient, mobile communication technology-based advisory services, and weather information are not available by the department (Mahmood et al., 2020). Farmers also adjust to climate change by engaging in animal production, enhancing agricultural output, selling cattle and crops, engaging in small businesses, participating in daily wage labour, horticultural cultivation, and non-agriculture occupations (Khan et al., 2024).

Further, sustainable agriculture under agroecological farming promotes diverse and complex agriculture applications by polyculture, rotations, agroforestry, utilise local seeds and breeds of cattle, increasing natural pest opponents, and operating composts and green manure to improve soil organic matter (Blackmore et al., 2021). Agriculture efficiency and manufacturing techniques differ in every agroecological zone in Ghana, Africa and crop farming in the forest zone is much better than in other zones. New maize cropping methods, for instance, a new variety of seeds, application of fertiliser, tractors, increasing cultivars created to specific agroecological zones, access to extension and financing, growers-based organisation, and applying monocropping boost crop yield in Ghana (Asante et al., 2019). Growers respond to changes in the season by agroecological zones with low-altitude but adjustments at the beginning of the wheat crop decline its productivity (Shah et al., 2021b). In these zones, organic farming is being supported in Egypt because it enhances environmental quality and promotes organic food. The arid and semi-arid areas of land are fostered by the collection of rainwater in this country. In North India, integrated farming techniques with cattle, sheep, goats, and fish farming offer organic manures for crops and these techniques provide feedstock (Sarkar et al., 2020).

Temperature and rainfall impact crop productivity differently under different Pakistan’s agroecological zones. The temperature and rainfall have affected wheat crop in the Northern irrigated plain. Similarly, the temperature has affected the Dry Mountains rice crop and the Indus Delta Zone's rainfall. In addition, temperature and rainfall have affected sugarcane crop in the Indus Delta Zone and have affected Northern dry mountains on maize crop (Hussain & Bangash, 2017).

3. Data Source & Methodology

3.1. Data

The paper will use panel data having ten agroecological zones of 18 districts spanning three provinces spanning different five time periods, most likely, 2000, 2005, 2010, 2015, and 2019, and source is taken from Pakistan's secondary sources, and variables are tractors in numbers, tapwater as percentage of households in rural areas, ownhouse as percentage of households possess, RRCC as a percentage of households construct roof with RCC, ELEC as %age of households having lighting. GASOIL is the percentage of households having Gas/Oil for cooking, BHUBeds represents the beds' numbers in basic health units, whereas Mintemp represents the lowest temperature. The Zones will be dummy variables to represent ten agroecological in every district as expressed by the FAO. The Sustainable Agriculture Index (SAI) will also be estimated based on revenue per hectare of each crop. The source of data is from development statistics of each province and Pakistan Social and Living Standards (PSLM).

Table 1: Agroecological Zones

Zones	Zone Name	Climate	Rainfall	Temperature	Soil	Crops
I	Indus Delta	Tropical Arid	Average 75mm per month in Summer and less than 5mm in winter	Summer temperatures range from 34 to 40^{0}C, while winter temperatures are 19 and 20^{0}C.	Clayey and silty	Rice, Sugarcane, Bananas, and Legumes
II	Southern Irrigated Plain or the Lower Indus Plain.	dry and subtropic al	In summer, it rains 18 millimeters to the north and 45-55 millimeters to the south per month.	---	The upper floodplain is calcareous loamy and clayey, whereas the lower portions are silty and sandy loam.	Cotton, wheat, and sugarcane are grown on the Indus River's left bank, while rice, wheat, and gram are grown on the right.
IIIa	Sandy Desert (a)	---	300 millimetres	---	Sandy andloamy fine	---
IIIb	Sandy Desert (b) Zone of sand ridges and dunes.	---	300-350 mm	---	Sandy andoamy fine	---
Iva	Northern Irrigated Plain (a) or Flood Plains and Bar Uplands	Semiarid to Arid	300-500 millimeters per year in the east, and 200-300 millimeters in the southwest per year.	---	Sandy, loam-clay, and loam.	Wheat, rice, sugarcane, oilseeds, and millets are the most common crops in the north, while wheat, cotton, sugarcane, maize, citrus fruits, and mangoes are popular in the middle and south.
Ivb	Northern Irrigated Plain (b) in the alluvial valleys of Peshawar and Mardan	Semi-dry	20-30 mm monthly	---	Silty clays and clay loams	Sugarcane, sugar beet, wheat, tobacco, berseem, maize, and orchard
V	Barani (rainfed) Lands	The southern portion is semi-dry and hot	85- millimetre200 millimetres in summer and 30-45 millimetres in winter.	---	The Salt Range and the Potwar Plateau	Wheat, millet, oilseed, and Pulses.
VI	Wet Mountains or High Mountains	---	235 millimeters summer, 116 millimeters winter, covered by forest, covered by rainfed agriculture	---	Silt loams to silty clays	---
VII	Northern Dry Mountains	---	25-75 millimetres each month in winter, 10-20 millimetres in summer each month	---	Deep and Clayey	The area serves for grazing.
VIII	Western Dry Mountains;	Barren Hills and Sloping Terrain	95 millimetre per month in summer and 63-95 millimetres per month in winter	---	deep and loamy	wheat and fruit crops are mature; the land is practised in favour of grazing
IX	Dry Western Plateau or mountainous territory	---	37 mm per month during summer; the coastal belt in this zone receives sea breezes.	---		melons, vegetables, fruit crops, and wheat; land practiced for grazing
X	Sulaiman Piedmont or Sulaiman Range	Arid and Hot Climate	Lower than 15 millimeters per month; irrigation is reliant on hill torrent flooding.	---`		wheat, millet, and gram

3.2. Sustainable Agriculture Index (SAI)

Agriculture is considered sustainable if the production or revenue per hectare of each crop within districts in three Pakistani provinces is sustained throughout time. The Sustainable Agriculture Index may be determined by standardizing the revenue per hectare of each crop.

The yield is standardised using the methods used by the United Nations Human Development Index (Guha et al., 2018; S. Singh & Nayak, 2020a; Sundar Pani & Mishra, 2022; UNDP, 2006)(Guha et al., 2018; S. Singh & Nayak, 2020a; Sundar Pani & Mishra, 2022; UNDP, 2006)(Guha et al., 2018; S. Singh & Nayak, 2020a; Sundar Pani & Mishra, 2022; UNDP, 2006). Therefore,

$$SAI_{ijt} = \frac{X_{ijt} - MIN_{ij}X_{ijt}}{MAX_{ij}X_{it} - MIN_{ij}X_{it}} \tag{1}$$

In this equation, i stands for crops (i=1, 2, 3,4, 5), j stands for districts of three Pakistani provinces (i=1, 2, 3, ….., 24), and t stands for five different time periods (t=2000, 2005, 2010, 2015, 2018); and $\boldsymbol{X_{ijt}}$ stands for the revenue per hectare of crop for the jth district; $\boldsymbol{MIN_{ij}X_{ijt}}$indicates the lowest amount of $\boldsymbol{X_{it}}$of district j; and $\boldsymbol{MAX_{ij}X_{it}}$ mentions the highest amount of $\boldsymbol{X_{ijt}}$of district j. The index will range from 0 to 1; when the index falls between 0.9 and 1, or near these levels, the jth district will be very sustainable with regards to ith crop. When the index falls between 0.5 and 0.8, the jth district will be suitable for the ith crop. When the index falls from 0.1 to 0.5, the jth district will be less suitable for the ith crop; and when the index falls to zero, the jth district will be unsuitable for the ith crop.

3.3. The econometric model is used *h*Panel Least Square Dummy Variable Regression:

The Panel Least Square Dummy Variable Regression Model (LSDV) is a modification of the Pooled Ordinary Least Square Regression Model (OLS), which covers data with cross-sectional or fixed effects that OLS does not. LSDV is expressed as:

$$Y_{ijt} = \beta_0 + \beta_i X_{ijt} + D_i \alpha_j + u_{it} \tag{2}$$

Y_{it} is the variable that is dependent, and X_{it} is the variable that is independent throughout the five different periods of time; $\beta_0$shows the intercept, and α_j shows the intercept of every district that is time-invariable; D_j denotes dummy variables (Abdulwakil et al., 2020; Amil et al., 2023; Baltagi, 2005; Dialga & Ouoba, 2022)ss(Abdulwakil et al., 2020; Amil et al., 2023; Baltagi, 2005; Dialga & Ouoba, 2022)ss(Abdulwakil et al., 2020; Amil et al., 2023; Baltagi, 2005; Dialga & Ouoba, 2022)ss.

The econometric model to assess the factors of sustainability will be as follows:

$$SAI_{ijt} = \beta_1 tractor_{jt} + \beta_2 tapwater_{jt} + \beta_3 ownhouse_{jt} + \beta_4 RRCC_{jt} + \beta_5 ELEC_{jt} + \beta_6 GASOIL_{jt} + \beta_7 \mathrm{BHUBeds}_{jt} + \beta_8 \mathrm{Mintemp}_{jt} + \alpha_i Zone_i + u_{it} \tag{3}$$

where SAI is the Sustainable Agriculture Index; tractor is the tractors in numbers; tapwater is to irrigate and drinking purposes; ownhouse means households possess their ownhomes; RRCC is the roof composed of RCC; ELEC is electricity in the household or running tubewells; GASOIL is utilized for cooking; BHUBeds refers to the beds in basic health units. Mintemp is the lowest temperature in every district, and zone refers to a dummy variable; 1 indicates that the district is in the corresponding agroecological zone, whereas 0 indicates that it is not in the same zone.

4. Empirical Results

4.1. Sustainable Agriculture Index (SAI)

The SAI Index of 2018-19 is shown in Table 2. Sahiwal, Rahimyarkhan, Bahawalpur, Layyah, and Sialkot districts in Punjab Province were stable for growing the wheat crop, and Rahimyarkhan is also highly suitable for growing the rice crop. Similarly, Rahimyarkhan was highly suitable to grow cotton and sugarcane crops, and the jawar crop were highly stable in the Sahiwal district and unstable in the Sialkot and Layyah Districts. The Sialkot district was hit by the flood 2018-19 and it devastated crops in this district.

In KP, districts Swat and Mardan were suitable to grow wheat crop, and districts Dera Ismail Khan and Swat were suitable to grow rice crop. Comparably, district D.I. Khan was ideal and favourable to grow sugarcane and jawar crops. The Swat district was also suitable to grow crop rotation for rice crop with wheat due to climatic favour. The Mardan district rotated crop wheat with jawar due to climatic change and flood (Fahad & Hashim, 2025).

In Sindh, the district Nawabshah was better at producing wheat and cotton crops and the Dadu district was suitable to grow Rice crop. The sugarcane was highly suitable in the Thatta, Nawabshah, and Shikarpur districts and the Jawar crop is highly stable in the Shikarpur district.

Table 2: SAI of 2018-19

	Wheat	Rice	Cotton	Sugarcane	Jawar
Punjab					
Rahimyar Khan	0.95	1.00	1.00	1.00	0.36
Sahiwal	1.00	0.43	0.29	0.47	1.00
Gujrat	0.00	0.00	---	0.00	0.03
Sialkot	0.54	0.22	---	0.22	0.00
Bahawalpur	0.86	0.16	---	0.65	0.18
Layyah	0.63	0.14	0.00	0.96	0.04
KP					
Abbottabad	0.71	---	---	---	---
Mardan	0.89	0.00	---	0.18	0.97
Swat	1.00	0.69	---	---	---
Dera Ismail Khan	0.69	1.00	---	1.00	1.00
Karak	0.00	---	---	---	0.00
Lakki Marwat	0.60	0.20	---	0.00	0.88
Sindh					
Thatta	0.00	0.00	0.11	1.00	0.35
Nawabshah	1.00	---	1.00	0.92	0.68
Sanghar	0.66	---	0.94	0.68	0.00
Tharparkar	0.16	---	0.00	0.00	---
Shikarpur	0.44	0.34	1.00	0.90	1.00
Dadu	0.61	1.00	0.83	0.47	0.92

Source: Authors' Estimation

The SAI Index of 2014-15 is shown in Table 3. Rahimyarkhan, Bahawalpur, and Layyah districts in Punjab were stable for growing the wheat crop, and district Rahimyarkhan was also suitable for growing rice crop. Further, Bahawalpur and Rahimyarkhan were suitable to grow sugarcane crops.

In KPK, districts Mardan, Swat, Abbottabad, Dera Ismail Khan, and Lakki Marwat were suitable to grow this crop, and the districts Swat and Dera Ismail Khan were again suitable to grow the cotton crop. Moreover, the district of Dera Ismail Khan was suitable to grow sugarcane crop. Likewise, the district of Mardan was highly sustainable in producing the jawar crop.

In Sindh, the district of Nawabshah was better at producing wheat crop. The district Shikarpur favourable to grow rice crop and the district sanghar was highly favourable to grow the cotton crop. The Dadu district was favourable to grow sugarcane crop and jawar crop.

The SAI Index of 2009-10 is shown in Table 4. Sahiwal and Bahawalpur districts in Punjab were highly stable for growing wheat crop and Rahimyarkhan was stable in growing rice, cotton, sugarcane, and jawar crop and Gujrat district was too stable in growing rice crops.

In KP, districts Mardan and Dera Ismail Khan were highly suitable to grow wheat crop. The district Dera

Ismail Khan too was highly suitable to grow rice crop and the district Mardan was highly suitable to grow sugarcane and jawar crops. As another study finds out, Mardan district rotated, during this year, wheat crop with sugarcane due to the positive benefits of climate (Fahad & Hashim, 2025).

In Sindh, districts Nawabshah and Sanghar were highly favourable to grow rice crop, and this crop was highly suitable to grow in district Shikarpur. The cotton crop was highly suitable in the district of Dadu, and sugarcane and jawar crops were highly suited in the Nawabshah district.

The SAI Index of 2004-05 is shown in Table 5. Sahiwal and Bahawalpur districts in Punjab were highly stable for growing the wheat crop. Rahimyarkhan was also stable in growing rice, cotton, sugarcane, and jawar crop, and the Gujrat district was as well stable in growing rice crop. The climatic conditions in these districts were modest and hence supported rice and sugarcane crop.

Table 3: SAI of 2014-15

	Wheat	Rice	Cotton	Sugarcane	Jawar
Punjab					
Rahimyar Khan	1.00	1.00	---	1.00	---
Sahiwal	0.00	0.38	0.79	0.72	---
Gujrat	0.39	0.00	---	0.52	---
Sialkot	0.32	0.13	---	0.42	---
Bahawalpur	0.89	0.18	1.00	0.79	---
Layyah	0.58	0.10	0.00	0.00	---
KP					
Abbottabad	0.82	---	---	---	---
Mardan	1.00	0.20	0.00	0.85	1.00
Swat	0.88	1.00	---	---	---
Dera Ismail Khan	1.00	0.76	1.00	1.00	0.57
Karak	0.00	---	---	---	0.00
Lakki Marwat	0.61	0.00	---	0.00	0.79
Sindh					
Thatta	0.03	0.00	0.15	0.02	0.45
Nawabshah	1.00	0.75	0.03	0.02	0.76
Sanghar	0.40	0.09	1.00	0.02	0.00
Tharparkar	0.00	---	0.00	0.004	---
Shikarpur	0.06	1.00	---	0.00	---
Dadu	0.29	0.85	0.65	1.00	1.00

Source: Authors' Estimation

Table 4: SAI of 2009-10

	Wheat	Rice	Cotton	Sugarcane	Jawar
Punjab					
Rahimyar Khan	0.83	0.41	1.00	1.00	0.61
Sahiwal	1.00	0.58	0.10	0.14	1.00
Gujrat	0.00	0.41	---	0.34	0.22
Sialkot	0.46	1.00	---	0.00	0.00
Bahawalpur	0.88	0.00	0.54	0.60	0.16
Layyah	0.70	0.43	0.00	0.54	0.02
KP					
Abbottabad	0.77	---	---	---	---
Mardan	1.00	0.88	---	1.00	1.00
Swat	0.77	1.00	---	---	---
Dera Ismail Khan	0.87	0.00	---	0.00	0.04
Karak	0.00	---	---	---	0.00
Lakki Marwat	0.17	---	---	0.84	---
Sindh					
Thatta	0.10	0.00	0.92	1.00	0.71
Nawabshah	1.00	0.27	0.39	0.25	1.00
Sanghar	0.76	0.03	1.00	0.80	0.36

Tharparkar	0.00	---	0.36	0.00	---
Shikarpur	0.05	0.50	---	0.34	0.00
Dadu	0.11	1.00	0.00	0.04	0.01

Source: Authors' Estimation

In KPK, districts Mardan and Dera Ismail Khan were highly suitable to grow wheat crop, and the district Dera Ismail Khan too was highly suitable to grow rice crop. The district Mardan was highly suitable to grow sugarcane and jawar crops.

In Sindh, districts Nawabshah and Sanghar were highly favourable for growing wheat crops and rice crops were highly suitable for growing in district Shikarpur. The cotton crop was highly suitable in the district Dadu and sugarcane and jawar crops were highly suited in the Nawabshah district.

Table 5: SAI of 2004-05

	Wheat	Rice	Cotton	Sugarcane	Jawar
Punjab					
Rahimyar Khan	0.81	1.00	1.00	1.0	1.00
Sahiwal	1.00	0.43	0.00	0.16	0.74
Gujrat	0.00	0.99	---	0.51	0.72
Sialkot	0.64	0.00	---	0.00	0.00
Bahawalpur	0.77	0.97	0.85	0.56	0.68
Layyah	0.90	0.62	0.14	0.81	0.74
KP					
Abbottabad	0.65	---	---	---	---
Mardan	1.00	0.00	---	1.00	1.00
Swat	0.80	0.65	---	---	---
Dera Ismail Khan	0.91	1.00	---	0.00	0.76
Karak	0.00	---	---	---	0.00
Lakki Marwat	0.39	---	---	---	---
Sindh					
Thatta	0.23	0.00	0.03	0.52	0.50
Nawabshah	0.99	0.21	0.07	1.00	1.00
Sanghar	1.00	0.42	0.08	0.70	0.75
Tharparkar	0.00	---	0.00	0.00	---
Shikarpur	0.36	1.00	---	0.10	0.00
Dadu	0.63	0.80	1.00	0.49	0.51

Source: Authors' Estimation

The SAI Index of 1999-00 is shown in Table 6. Sahiwal district in Punjab was highly stable for growing wheat crop and district Layyah was also stable for growing rice and jawar crops. In the same way, the cotton crop was highly stable to grow in the Bahawalpur district and the sugarcane crop was highly favourable to grow in the Sialkot district. Sahiwal, Bahawalpur, and Rahimyarkhan districts were also more stable in growing jawar crop.

In KPK, the wheat crop was highly supported in the soil of district Mardan, and unsupported to grow in the district Karak. District D.I. Khan is too favourable for growing rice and cotton crop. Furthermore, district Mardan was favourable to grow sugarcane, and jawar crops

In Sindh, the district Nawabshah was better at producing wheat crop, and the district Shikarpur was favourable to grow rice crop. Cotton, sugarcane, and jawar crops were highly suitable to grow in the district of Nawabshah.

4.2. Least Square Dummy Variable Model (LSDV):

Table 7 reveals the LSDV findings. The variable that is dependent is SAI of the wheat crop. Ownhouse, RRCC, and ELEC are correlated positively and significantly to the SAI of the wheat crop that means these variables have positive impact and it indicates, households have more modern houses than traditional (made up of grass, wood), and have electricity to run tubewell and to increase wheat crop yield. But

Mintemp has a negative association with this index. It means that a 1% change in Mintemp decreases the wheat crop. Tractors are insignificant with the wheat crop SAI index because the farmers are using traditional tractors with high diesel consumption, so, adopting these tractors are not significant to produce wheat crop. Our results are inconsistent with previous studies (Haseeb Raza et al., 2019). The Sandy Desert Zone (Zone III) is significant with the SAI index of wheat but the climatic minimum temperature changes have negative impact on this crop. This is in contrast with the previous study result where this zone was suitable for rice crop (Abdullah et al., 2022).

Table 8 shows the LSDV model results for the SAI of the rice crop. The RRCC and BHUBeds are significant and positively associated with the SAI of rice crop. In contrast, GASOIL is significant and negative with the SAI of rice crop because most small farmers do not have access to GASOIL. The rice crop is well suited to the Northern Dry Mountains (Zone VII). This again does show the same results as previous studies (Abdullah et al., 2022).

Table 9 depicts the findings of the LSDV for cotton. Mintemp is correlated and positive to the SAI index of the cotton crop. Most of the variables in this study are insignificant, which shows cotton can be produced, as SAI Tables show, in Sanghar district due to unfavourable climatic conditions and an increase in the salinity problem. Otherwise, it can be produced in crop rotation and intercropping pattern with other crops. This crop is suited to the Northern Irrigated Plain (Zone IV).

Table 10 reveals the same model findings for sugarcane. ELEC and Ownhouse are positively related and significant to the SAI of sugarcane crop. The Sandy Desert Zone (Zone III) is significant with the SAI index of sugarcane crop and it means that this crop is suitable to grow in this zone.

Table 6: SAI of 1999-00

	Wheat	Rice	Cotton	Sugarcane	Jawar
Punjab					
Rahimyar Khan	0.60	0.57	0.50	0.53	0.94
Sahiwal	1.00	0.32	0.55	0.00	1.00
Gujrat	0.00	0.00	---	0.85	0.51
Sialkot	0.51	0.15	---	1.00	0.00
Bahawalpur	0.66	0.37	1.00	0.71	0.90
Layyah	0.15	1.00	0.00	0.43	1.00
KP					
Abbottabad	0.61	0.00	---	---	0.93
Mardan	1.00	0.41	0,00	1.0	1.00
Swat	0.46	0.77	---	0.0	---
Dera Ismail Khan	0.59	1.00	1.00	0.84	0.92
Karak	0.00	.	---	---	0.00
Lakki Marwat	0.16	0.35	---	0.69	---
Sindh					
Thatta	0.0	0.12	---	0.82	0.00
Nawabshah	1.0	0.40	1.00	1.00	1.00
Sanghar	0.66	0.00	---	0.00	0.66
Tharparkar	---	---	---	---	---
Shikarpur	0.16	1.00	0.00	0.52	0.28
Dadu	0.26	0.91	0.70	0.71	0.45

Source: Authors' Estimation

Table 7: SAI of Wheat Crop

	All Variables		
	Coef.	**Std.Err.**	**P>|t|**
Tractors	-0.001	0.002	0.461
Tapwater	0.006	0.005	0.221
Ownhouse	0.004	0.002	0.041
RRCC	0.005	0.002	0.005
ELEC	0.013	0.002	0.000
GASOIL	-0.005	0.003	0.103
BHUBeds	0.004	0.004	0.426

Mintemp	-0.051	0.024	0.035
Zone_I	0.015	0.149	0.918
Zone II	-0.462	0.245	0.066
Zone III	0.761	0.158	0.000
Zone IV	-0.074	0.086	0.394
Zone_V	-0.591	0.174	0.001
Zone VI	0.00	---	
Zone VII	-0.469	0.181	0.013
Zone VIII	-0.084	0.173	0.629
Zone IX	0.229	0.229	0.322
Zone X	0.334	0.331	0.319
Constant	0.038	0.337	0.911

Source: Authors' Estimation

Table 11 represents the result of the Jawar crop. BHUBeds and Tractors are positively related and significant to the SAI of jawar crop. Nevertheless, Mintemp and SAI of the jawar crop have a negative association. The Sandy Desert Zone (Zone III) and Zone IX (Dry Western Plateau) are suitable to grow jawar crop.

Table 8: SAI of Rice Crop

	All Variables		
	Coef.	**Std.Err.**	**P>|t|**
Tractors	0.001	0.003	0.792
Tapwater	-0.003	0.018	0.674
Ownhouse	0.003	0.012	0.155
RRCC	0.010	0.004	0.031
ELEC	0.007	0.006	0.280
GASOIL	-0.013	0.006	0.037
BHUBeds	0.010	0.006	0.074
Mintemp	0.019	0.043	0.658
Zone I	-0.058	0.226	0.800
Zone II	0.481	0.292	0.109
Zone III	-0.413	0.235	0.095
Zone IV	0.182	0.165	0.277
Zone V	-0.071	0.316	0.824
Zone VI		---	
Zone VII	0.591	0.340	0.091
Zone VIII		---	
Zone IX	0.149	0.215	0.493
Zone X	-0.624	0.551	0.266
Constant	-1.188	1.222	0.338

Source: Authors' Estimation

Table 9: SAI of Cotton Crop

	All Variables		
	Coef.	**Std.Err.**	**P>|t|**
Tractors	0.01	0.00	0.12
Tapwater	0.01	0.02	0.58
Ownhouse	0.00	0.00	0.79
RRCC	0.01	0.01	0.32
ELEC	0.00	0.00	0.59
GASOIL	0.02	0.01	0.12
BHUBeds	-0.01	0.01	0.32
Mintemp	0.15	0.06	0.04
Zone I	-0.08	0.26	0.77
Zone II	-0.11	0.56	0.84
Zone III	0.53	0.52	0.32
Zone IV	0.51	0.19	0.01
Zone V		---	

Zone VI		---	
Zone VII		---	
Zone VIII		---	
Zone IX		---	
Zone X		---	
Constant	-3.19	1.21	0.02

Source: Authors' Estimation

Table 10: SAI of Sugarcane Crop

	All Variables		
	Coef.	**Std. Err.**	**P>|t|**
Tractors	0.003	0.002	0.101
Tapwater	0.011	0.010	0.261
Ownhouse	0.007	0.003	0.054
RRCC	0.004	0.003	0.203
ELEC	0.007	0.003	0.030
GASOIL	0.004	0.006	0.520
BHUBeds	0.007	0.007	0.345
Mintemp	0.334	0.228	0.151
Zone I	-0.381	0.239	0.120
Zone II	0.529	0.181	0.006
Zone III	0.204	0.131	0.126
Zone IV	-0.555	0.192	0.006
Zone V	0.334	0.228	0.151
Zone VI	0.00	---	
Zone VII	0.091	0.460	0.844
Zone VIII	0.00	---	
Zone IX	0.211	0.333	0.531
Zone X	0.00	---	
Constant	-1.046	0.738	0.165

Source: Authors' Estimation

Table 11: SAI of Jawar Crop

	All Variables		
	Coef.	**Std. Err.**	**P>|t|**
Tractors	0.004	0.002	0.096
Tapwater	-0.011	0.009	0.215
Ownhouse	0.020	0.016	0.216
RRCC	0.006	0.013	0.108
ELEC	0.000	0.006	0.991
GASOIL	-0.004	0.003	0.229
BHUBeds	0.011	0.006	0.055
Mintemp	-0.067	0.034	0.055
Zone I	-0.519	0.234	0.035
Zone II	-1.369	0.218	0.000
Zone III	0.778	0.157	0.000
Zone IV	-0.074	0.105	0.489
Zone V	-1.224	0.258	0.000
Zone VI	0.000	---	
Zone VII	0.153	0.400	0.706

Zone VIII	0.183	0.240	0.453
Zone IX	0.805	0.368	0.037
Zone X	0.00	---	
Constant	0.230	1.513	0.880

Source: Authors' Estimation

5. Conclusion and Policy Implications:

This study paper has gauged the Sustainable Agriculture Index (SAI) of each crop revenue per hectare throughout five different times in three provinces' 18 districts of Pakistan. The study has analysed the association of economic, social, and environment indicators with the SAI index by estimating the Least Square Dummy Variable (model) to determine the sustainable agriculture of each crop in ten agroecological zones and these 18 districts in five periods.

According to the SAI Index, Sahiwal and Bahawalpur districts in Punjab province, Mardan in KPK province, and Nawabshah district in the Sindh province are stable to grow wheat crop except for the 1999-00 and 2014-15 floods. Not any district is suitable to grow rice and cotton crops because climate change and flood and earthquake impact.. The sugarcane crop and jawar crop are suitable to grow in the district of Rahimyarkhan. However, the above crops are not suitable to grow in the KPK province and the Sindh province.

The study also estimated the LSDV model and found that Ownhouse, RRCC is positively and significantly related to the SAI of the wheat crop and rice crop, and ELEC is also positively and significantly related to the SAI of the wheat crop, rice crop, and sugarcane crop. Similarly, the BHUBeds is positively and significant related to the SAI of rice and jawar crop. In the same way, Mintemp is positively and significantly related to the SAI of the cotton crop, and Ownhouse is positively and significantly related to the SAI of the sugarcane crop. In the same way, Tractors have a positive significant impact on the SAI of the jawar crop. On the other hand, Mintemp is negatively associated with the SAI index of wheat crop and jawar crop, but positively associated with rice and cotton crop; GASOIL is negatively significantly correlated with the SAI index of rice crop.

The Sandy Desert Zone (Zone III) is suitable for growing wheat crop, sugarcane crop, and jawar crop, and the Northern Dry Mountains (Zone VII) is suitable for growing rice crop. The Northern Irrigated Plain (Zone IV) is favourable for the cotton crop, and the Dry Western Plateau zone is suitable for growing the jawar crop.

In conclusion, the wheat crop is somewhat sustainable to produce in Pakistan's districts but some important social variables like Tapwater, and BHUBeds are insignificant with the wheat SAI index. Similarly, rice and cotton crops are not sustainable to grow in any district, and sugarcane and jawar crop are not sustainable in all economic, social, and environment indicators.

For the policy option, the farmers should change their farming strategy and use a climate adaptation strategy based on agroecological zones. This cropping uses organic manure for fertiliser, green manure, mulching, and cropping rotation are some strategies for climate change. Farmers must also use drought and water-resistant seeds and enhance water conservation and storage techniques. Farmers should also adopt climate-resilient crops to tackle climate change and sustainable farming in agroecological zones. The climate change has changed the pattern of cropping, and the season has shortened as compared to 20 years before, so, wheat and gram crops sowing period should be delayed in order to get benefits of these crops. Policymakers should support small farmers via subsidies to adopt modern technologies, seed, adaptation and mitigation to climate change. The extension department should be more active to rationalise farmers' capacity in order to take advantage of more climate information, adaptation and mitigation. One must support corporate farming, but this farming will displace subsistence and small farmers and will increase the vacuum of more labour without absorbing by the market.

The research has its own limitations. It has not estimated cost of inputs to support how farmers get hurt from these variables. It has also not incorporated modern technology and climate adaptation strategy in zones. Future research should cover these areas with the support of a more active extension department of the government. New agroecological zones should be devised to enhance new cropping patterns and varieties with climate change.

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Disclaimer

In this paper, the research and opinions are expressed by the authors alone and it does not show the views of any institution.