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Assessment of Agricultural Performance of Districts of Punjab Based On Composite Agricultural Indicators Using Grey Relational Analysis

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Abstract *The province of Punjab is considered the breadbasket of Pakistan. This study is aimed to evaluate and hierarchicalize the districts of Punjab based on agricultural indicators. It follows a ranking approach that uses secondary cross-sectional data obtained from Punjab Development Statistics 2016. This study has employed Grey System Theory and used GRA. It is a seminal study that uses a unique methodology that has integrated thirteen different indicators of agricultural development in one mathematical model and assigned a distinct composite grade to every district. Findings revealed that district Bahawalpur and Bahawalnagar have the highest Grey Relational Grade (GRG), hence depict the best agricultural performance in Punjab, whereas district Mianwali has the lowest GRG and accordingly least performance. This research provides insight to the policymakers, which will help them to take corrective measures and/or adjust the agricultural development policies.*

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Introduction

Across the world, it is witnessed by economists that agriculture plays a fundamental role in the economic achievements of a country. But in modern days, the share of agriculture is waning that ultimately led to a lower rate of saving and employment. Kirby et al. (2017) have defined that in Pakistan, forty-seven per cent of the population is food insecure, and food production mainly depends on traditional irrigation system from already stressed water resources. This largely is due to the higher elasticity of demand in non-agriculture products and services. Agriculture subsidiaries like crops, dairy, fisheries and animal husbandry are a major source of income in Pakistan (GOP, 2017). Agriculture is a relatively well-developed sector of Pakistan's economy since Pakistan's independence, and it is considered as a driving wheel of the economy. It accounts for nineteen per cent of GDP (GOP, 2017) and directly supports more than half of the total population. Pakistan is heavily dependent on its major crops. The main crops of Pakistan include cotton, sugarcane, rice and wheat. Pakistan has one of the world's largest irrigation systems to support the production of its agricultural crops. There are mainly two seasons for the production of crops, i.e. May to November and November to April. The crops of cotton, sugarcane and rice are sown in May and harvested in November, whereas the crop of wheat is sown in November and harvested in April. There is an extensive production gap between the actual and required output of production due to the low level of knowledge of peasants about modern and efficient agriculture systems (Aslam, 2016). Declining water resources (Faruqui, 2004), un-equal land fertility and less education about pest and plant diseases control are other reasons for the said gap (Amanullah et al., 2009; Yang et al., 2005; Kamal & Moghal, 1968). Unwisely use of fertilizers, and modern machinery in the agricultural sector is yet another reason for this mismatch that underpins the urgent need for

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efficient resource utilization (Rehman et al., 2016).

Punjab is a major province of Pakistan, largest by population and second-largest by area. It has 36 districts, with Lahore being its capital. Punjab has a population of 99.9 million people, i.e. 57 % of the total population of Pakistan. This province has 57% cultivated and 69% of the total crop sown area in Pakistan. Its contribution to the agriculture of the economy of Pakistan is 83% of cotton, 80% of wheat, 97% of rice, 63% of sugar cane and 51% of maize. Agriculture is the main source of income for almost 77% of people in Punjab. Agriculture resources mainly include land and water to produced crops of wheat, cotton, rice and sugar cane. These crops account for more than 75% of the value of total crop production (Finance Division; Govt. of Pakistan, 2015). The crops under study account for 64 % of the annual crop area and about 90 % of major agricultural crops in Pakistan (Finance Division; Govt. of Pakistan, 2015).

Wheat is a major cereal crop in Pakistan, particularly in Punjab. It occupies 37% of crop area and 45% of other agricultural resources (Amanullah et al., 2019). It involves investment in canal irrigation and market development. Wheat has a total share of 14% in agriculture. Punjab followed the green revolution movement in the production of wheat since 1965, due to which wheat per hectare production has increased, and rural society has transformed (Hussain et al., 2002). Despite all revolutionary measures, Punjab Government still needs to reform wheat production in various varieties (Smale et al., 2002). Rice is the second major crop of Pakistan. It is being exported worldwide from Pakistan, which accounts for approximately 10% of the world's trade annually. Only basmati rice has a share of 25% of Pakistan exports. Rice export is the second major source of income in Pakistan that fulfils at least 60% of food need. Cotton is another major cash crop in Pakistan. Pakistan efficiently plays the role of raw cotton producer (Khan & Khaliq, 2010). Cotton exports account for 46% of total exports, and it engages 35% of labour. Production has increased by multiple times from 1952 to 2004 (Ali et al., 2013). Although Punjab and Sindh are the major producers of cotton in Pakistan, Punjab province is the leading producer with a larger cultivated area. Out of total production, more than 80 % comes from Punjab, whereas only 18 % comes from Sindh. Sugar cane is also one of the most important cash crops of Pakistan and the driver of the sugar industry in Pakistan. It accounts for 0.7% of GDP and 3.7% of agriculture value (Godfray et al., 2010), and in rural areas, sugarcane cultivation is a major sign of socioeconomic development because it provides high income and employment opportunities.

Statement of Problem

The above representation on agriculture reveals that a lot of research has already been surpassed on evaluation of overall production of agricultural crops and their contribution to GDP. However, little research work has been conducted about performance evaluation of administrative units or constituencies. It has become imperative and important to assess the contribution of administrative units (particularly at the level of districts) that to what extent they are efficient to contribute to GDP. It is a crucial decision to evaluate geo-politics using a multitude of indicators instead of anyone measure (Latruffe et al., 2016). Therefore, this study aims to evaluate the performance of the districts of Punjab. It focuses on providing insight for formulating policies regarding sustainable food security, making the agriculture process cost-effective and wisely use of fertilizers and modern machinery in the agricultural sector (Amanullah et al., 2019). The rest of the paper is arranged into the literature review, methodology, data analysis and concluding remarks.

Review of Literature

There is an influx of literature on agricultural performance and sustainability at countries' level and/or provinces' level, but there is scarcity at divisional and district levels, particularly with reference to Pakistan. Therefore, a fairly rigorous literature review has been conducted that provides plausible ground for this comparative study of agricultural performance. The relevant studies are therefore iterated. Anastasia and Wim (2017) conducted a research study in Russia using secondary data from Federal State Statistics Service and evaluated different municipalities. It emphasized that there are only a few studies evaluating the agricultural performance of different territories like municipalities despite the fact that it is important to study them in comparison using composite indicator indices. Gezici and Hewings (2004) carried a research study in Turkey using the secondary data of the Istanbul Chamber of Industry and data of the State Statistics Institute. It compared different regions of Turkey from an economic perspective. Trukhachev et al. (2014) proclaimed that it is crucial for the economies to evaluate their constituents on an objective basis. This study was conducted on the comparative agricultural performance of different federal district regions of Russia. It used archival statistical secondary data. This study used mixed methods for data analyses and accentuated the importance of comparison of districts on the basis of agriculture production. Talukder et al. (2017) carried a research study on indicators of agricultural performance. They asserted that there are more than fifty indicators of agricultural performance that can be categorized into productivity, stability, efficiency, durability, compatibility and equity. There is also a large array of techniques for measuring the integrated performance of agricultural units. It also argued that it is important to determine which indicator to include, what weight to be given to each indicator and what technique of analysis to be employed in order to fairly represent the comparative regional positions. This study used composite normalization, weighting and aggregation techniques on primary and secondary data and recommended rather different and relatively newer techniques of analyses to obtain fairly generalizable results.

Literature is rich in different aspects of agriculture; Lewis (2017) stated that agriculture always played a key role in economic growth and eliminating food insecurity. In various economies, household's income is primarily based on agriculture and their ability to exploit natural resources efficiently (Hussain et al., 2015). Keesstra et al. (2016) evaluated that the world population was growing fast in the last few decades, and food resources were shrinking that exposed the world to a challenge that how to properly utilize available resources, particularly soil, water and natural fertilizers. Araya et al. (2021) found that to counter these emerging challenges, they need to use available resources wisely. Due to probable food insecurity, it is perilously significant and resultantly irresistible for developing countries (Lewis, 2017). Borrelli et al. (2015) inclined that ever-mounting population strain on planet and decreasing water resources leading to filth condition of these resources. Fahad et al. (2017) have employed analysis of covariance to evaluate the genetic diversity in wheat crop production with respect to enhancement in production. Results found positive relation among studied variables. This results in the shape of reduced productive capacity, soil degradation, soil erosion and teeming food insecurity. Tanveer et al. (2017) asserted that soil degradation and depletion of natural resources is one of the most high-flying challenges for the modern agriculture sector. Byerlee et al. (2009) stated that the low share of agriculture in economic development and in GDP has a foreseeable upshot in economic progress. According to the agricultural economies witnessed a fall in food production due to low-income elasticity of demand of agriculture production. Maraşlıoğlu (2017) bolstered that scarcity of water resources is the major factor for limiting agriculture development, and it drastically affects food production. Under changing climate, conserving soil and water resources are critical and important to sustain the agriculture sector. It is important to highlight that scarcity of water will alternatively lead to the overuse of underground water, consuming a lot of energy to pumping it out, whereas Pakistan is already having a problem of an energy shortage, specifically in rural areas. Ladha et al. (2003) buttressed that rice is one of the most important food crops in Pakistan. Jalota et al. (2018) concluded that in central Punjab of India, more groundwater withdrawal to irrigate rice, and wheat crop lead to the reduced water table. By improving the irrigation system, shifting planting date, and laser levelling reduced the water losses. Gangwar and Prasad (2005) claimed that in the last few years, both systems suffered from belated planting of subsequent crops resulting in loss of crop yield. Losses can be reduced with a proper cropping system. Khan and Khaliq (2005) found that wheat crop sown before cotton significantly gives a high yield then it is harvested after cotton. It is attributed to high plant density, more fertile tillers and grain spike. Watoo and Mugera (2014) stressed that tube well users and water buyers could enhance their production by 19% and 28% with the use of quality inputs as seeds or fertilizers. Cotton production in Pakistan is directly dependent on fertilizers price, competing for crop price and fertility of the land. Ali et al. (2017) argued that in addition to all these factors, there is a need to educate farmers, enhance credit facilities and improve transportation. Ali et al. (2013) suggested that there is a severe need to educate growers about plant protection measures and the use of fertilizers to get higher production of cotton.

Theoretical Framework

Copious literature has been surpassed on evaluation of production of (output) wheat, cotton, rice and sugar cane along with inputs, e.g. fertilizers, tube wells, harvesters, mounters, reapers, pumps etc.

However, the researchers could not find any study that has evaluated major crops along with their inputs with reference to administrative units of Punjab. Deng (1982) introduced revolutionary grey system theory with its analytical methodology, grey relational analysis. This approach is specifically used to cross analyze a multitude of variables and to evaluate the best alternatives in multi-criteria decision making. The main goal of the theory is to calculate the grey relational coefficient and obtain a grey relational grade among variables in order to evaluate the vague research problems (Ju-Long, 1982). This theory was first introduced for science discipline only, but with the passage of time, it came out as a bridge between natural and management sciences (Liu & Lin, 2010). It is now known as an inter-disciplinary approach. (Chen & Ting, 2002) argued that a grey system exists between black and white systems where white means information needed is exactly available and black system means information that is needed but not available. Therefore, it is “grey”. Under a grey system, a connection is established to discover values that are not clear or poorly stated (Hussain et al., 2002). It has five components in grey system theory, including grey predictions, grey decisions, grey programming, grey control and grey relational analysis. Grey Relational Analysis (GRA) is a popular method used with discrete data set. It is a mathematical technique useful in decision making of multi attribute cases. The advantage of GRA is that it is based on real data, simple mathematical calculation and one of the highest reliable methods of decision making in the business world (Chen & Ting, 2002). It quantitatively compares the variable in a vibrant way and establishes the relationship among variables based on similarity and inconsistency. In the past, GRA was used to evaluate: behaviour of energy consumption (Yu et al., 2011), decision making in the fuzzy system (Alcantud, 2018), supplier selection (Yang & Chen, 2006), portfolio selection (Bijarniya et al., 2020), software project performance evaluation (Shepperd & MacDonell, 2012) , safety assessment of e-commerce system (Radziszewska, 2018), wealth management (Wu et al., 2010) and medical data analysis (Xuerui & Yuguang, 2004). Ertugrul and Prof (2016) stated that grey relational grade is used to assess the degree of relationship among factors. Kao and Hocheng (2003) asserted that grey relational analysis helps to analyze the uncertainties and disparities effectively. In contemporary research, authors used various Multi-Criteria Decision-Making Techniques (MCDMT) to evaluate the financial and economic performance of various firms and countries, such as a technique for order of preference by similarity to an ideal solution, analytical hierarchy process, and data envelopment analysis etc. depending upon the nature of the problem under study it was found appropriate to use GRA (one of the techniques from MCDMT). Grey relational theory is used to employ GRA in order to rank the performance of districts of Punjab with respect to agricultural indicators.

Methodology

This study follows the positivist research philosophy with a deductive approach. It is a cross-sectional study based on secondary data taken from Punjab Development Statistics 2016. It follows the mono method mathematical approach, i.e. GRA. To evaluate the agricultural performance of districts of Punjab, grey relational system theory is used. Dogan (2013) revealed that this system is frequently employed to use incomplete and impure information for analyzing the relations among a multitude of variables. Other statistical techniques like regression analysis could also be used to measure the performance of the agriculture sector, but these have many limitations as a large amount of data is needed, which generates an unsatisfied level of results (Uckun et al., 2012). The Grey relation system is an appendage to all those typical statistical techniques. GRA progresses stepwise, i.e. seven steps in accordance with Kuo et al. (2008); Wu (2002); Hamzacebi et al. (2011); Niazi et al. (2021), and Tayyar et al. (2014).

In the first step, data of all districts were obtained from Punjab Development statistics

2016, followed by the creation of reference series and comparable sequence in the next step. Reference series was formed by identifying the best alternative from the normalizing matrix. In the next (third) step, a normalized matrix was created, i.e. a single data set for healthy comparing and grey relation generation (Tsai et al., 2003). In this study, all four major crops and total area of sown was taken as larger the better degree because the more crops production we have, the better it is. However, other indicators like electric pumps, diesel pumps, tube wells, tractors, threshers, harvester, mounter were normalized on ideal value criteria as these variables are considered to use an ideal amount, not less or more in quantity. Normalized values of fertilizers were obtained by using "smaller the better" criteria as fertilizers are the cost of production, and in economic production, it is needed to use the least available cost and produces more output from it. Subsequently, absolute values were obtained in step 4 by calculating the deviation sequence. A deviation sequence is created to show how much a value can differ from its desirable value of series. Absolute values were created with the difference in the reference sequence and comparable sequence. Step 5 was completed by establishing a co-efficient matrix of grey relation system. Grey relational grade was calculated in the ensuing step, which is equal to all weighted sum of values, and the value with the highest grade is selected as the best alternative choice. In the final step, grey relational grades of all districts were arranged in ascending order to get the highest and lowest grades, respectively.

Following steps of GRA were used to access the best performer among different districts of Punjab:

Step 1: Created a data set and established a decision matrix of data set using the following formula:

$$x_i(k) = \begin{bmatrix} x_1(1)x_1(2) & \cdots & x_1(m) \\ \vdots & \ddots & \vdots \\ x_n(1)x_n(2) & \cdots & x_n(m) \end{bmatrix}$$

Eq. (1)

Where i=1, 2, 3…………n k = 1, 2, 3 ……….m

Table 1. Statistics of Agricultural Performance of Districts of Punjab

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_1	137	3696	20356	18954	14900	7239	7	2846	704	10	280	21	905
γ_2	122	2024	30082	25426	16355	6786	0	3994	837	66	239	14	1161
γ_3	226	3862	43899	40837	19597	7433	2	2458	834	27	219	126	1026
γ_4	96	729	19950	15630	4466	2439	0	613	420	43	109	7	558
γ_5	76	622	56749	44117	6863	4400	0	1197	543	12	54	14	594
γ_6	102	1429	57891	48037	11313	2873	6	616	671	40	142	45	875
γ_7	77	779	34577	15404	4078	4555	0	729	349	2	144	28	495
γ_8	109	4731	24119	27093	15452	6839	1	340	701	31	30	104	978
γ_9	50	5060	10192	0	0	1898	0	220	306	41	2	38	348
γ_{10}	106	7548	41423	51292	13801	4505	192	251	633	53	36	47	932
γ_{11}	72	2716	17074	15586	11383	4166	0	1087	427	39	43	39	554
γ_{12}	124	11889	51995	50191	14038	3865	0	1729	534	238	0	2	633
γ_{13}	26	4734	23825	23580	7381	3990	1	1183	313	49	0	2	243
γ_{14}	43	3016	24798	25566	5571	974	0	581	344	123	0	5	499
γ_{15}	71	2018	50493	43116	6889	2894	0	580	320	74	1	21	352
γ_{16}	45	3436	42898	35946	5744	3596	0	285	290	75	0	1	288
γ_{17}	52	6365	60405	58768	12373	3790	0	1285	410	140	0	1	362
γ_{18}	47	2001	2717	5829	5779	1666	11	147	170	40	0	0	164
γ_{19}	90	8081	21557	18687	12013	5049	109	248	511	84	11	33	514
γ_{20}	52	3478	15505	0	0	1861	5	377	312	109	1	15	420
γ_{21}	65	4269	26746	46949	14962	2290	5	402	518	200	0	3	712
γ_{22}	197	3511	9846	15474	8738	4100	2	356	453	17	146	3	577
γ_{23}	121	4713	14571	18719	11082	4997	0	613	545	24	191	7	642
γ_{24}	116	4424	4648	10103	9132	3105	0	923	457	6	199	2	637

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
γ_{25}	161	7995	10684	16877	14075	5482	0	1494	638	31	208	16	899
γ_{26}	31	288	286	904	5746	2128	1	292	227	0	0	0	179
γ_{27}	5	915	1160	3147	6369	3359	0	745	242	0	0	0	301
γ_{28}	15	3701	3504	3481	6328	3142	0	1430	260	0	0	0	198
γ_{29}	5	585	8384	4999	2939	884	4	91	110	1	0	0	107
γ_{30}	92	3953	12948	15737	12596	5357	6	484	447	29	81	6	462
γ_{31}	173	5974	31280	31910	11389	4886	0	457	613	144	20	14	711
γ_{32}	97	9915	7806	13873	8744	5427	0	802	417	54	51	3	519
γ_{33}	51	1744	46197	35164	13070	6488	11	572	701	42	8	60	509
γ_{34}	47	1245	44095	29978	7826	2953	0	1228	847	1	48	22	412
γ_{35}	10	531	12068	8287	4928	2044	17	93	440	25	1	8	171
γ_{36}	29	1282	10437	8910	4705	2673	3	861	363	7	58	3	323

Step 2: Created reference series and comparison matrix using formula:

$$x_{o} = [x_o(k), \ldots\ldots\ldots\ldots x_o(n)] \qquad Eq. (2)$$

Where $k = 1, 2, \ldots\ldots, n$

Reference series is formed with identifying best alternative from normalized matrix which is added to decision matrix to make a comparison among alternatives.

Table 2. Reference Series Generation

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
γ_0	5	3702	24866	23016	9184	3893	11	878	847	238	280	126	1161
γ_1	137	3696	20356	18954	14900	7239	7	2846	704	10	280	21	905
γ_2	122	2024	30082	25426	16355	6786	0	3994	837	66	239	14	1161
γ_3	226	3862	43899	40837	19597	7433	2	2458	834	27	219	126	1026
γ_4	96	729	19950	15630	4466	2439	0	613	420	43	109	7	558
γ_5	76	622	56749	44117	6863	4400	0	1197	543	12	54	14	594
γ_6	102	1429	57891	48037	11313	2873	6	616	671	40	142	45	875
γ_7	77	779	34577	15404	4078	4555	0	729	349	2	144	28	495
γ_8	109	4731	24119	27093	15452	6839	1	340	701	31	30	104	978
γ_9	50	5060	10192	0	0	1898	0	220	306	41	2	38	348
γ_{10}	106	7548	41423	51292	13801	4505	192	251	633	53	36	47	932
γ_{11}	72	2716	17074	15586	11383	4166	0	1087	427	39	43	39	554
γ_{12}	124	11889	51995	50191	14038	3865	0	1729	534	238	0	2	633
γ_{13}	26	4734	23825	23580	7381	3990	1	1183	313	49	0	2	243
γ_{14}	43	3016	24798	25566	5571	974	0	581	344	123	0	5	499
γ_{15}	71	2018	50493	43116	6889	2894	0	580	320	74	1	21	352
γ_{16}	45	3436	42898	35946	5744	3596	0	285	290	75	0	1	288
γ_{17}	52	6365	60405	58768	12373	3790	0	1285	410	140	0	1	362
γ_{18}	47	2001	2717	5829	5779	1666	11	147	170	40	0	0	164
γ_{19}	90	8081	21557	18687	12013	5049	109	248	511	84	11	33	514
γ_{20}	52	3478	15505	0	0	1861	5	377	312	109	1	15	420
γ_{21}	65	4269	26746	46949	14962	2290	5	402	518	200	0	3	712
γ_{22}	197	3511	9846	15474	8738	4100	2	356	453	17	146	3	577
γ_{23}	121	4713	14571	18719	11082	4997	0	613	545	24	191	7	642
γ_{24}	116	4424	4648	10103	9132	3105	0	923	457	6	199	2	637
γ_{25}	161	7995	10684	16877	14075	5482	0	1494	638	31	208	16	899
γ_{26}	31	288	286	904	5746	2128	1	292	227	0	0	0	179
γ_{27}	5	915	1160	3147	6369	3359	0	745	242	0	0	0	301
γ_{28}	15	3701	3504	3481	6328	3142	0	1430	260	0	0	0	198

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_{29}	5	585	8384	4999	2939	884	4	91	110	1	0	0	107
γ_{30}	92	3953	12948	15737	12596	5357	6	484	447	29	81	6	462
γ_{31}	173	5974	31280	31910	11389	4886	0	457	613	144	20	14	711
γ_{32}	97	9915	7806	13873	8744	5427	0	802	417	54	51	3	519
γ_{33}	51	1744	46197	35164	13070	6488	11	572	701	42	8	60	509
γ_{34}	47	1245	44095	29978	7826	2953	0	1228	847	1	48	22	412
γ_{35}	10	531	12068	8287	4928	2044	17	93	440	25	1	8	171
γ_{36}	29	1282	10437	8910	4705	2673	3	861	363	7	58	3	323

Step 3: Created a normalized matrix using the following formulas and prepare table 3:

$$\text{Larger the better } x_{i(k)} = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad \text{Eq. (3)}$$

$$\text{Smaller the better } x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(y) - \min x_i(k)} \quad \text{Eq. (4)}$$

$$\text{Ideal the better } x_i(k) = \frac{x_i(k) - x_i b(k)}{\max x_i(k) - x_i b(k)} \quad \text{Eq. (5)}$$

Table 3. Normalization of Values

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_0	0.00	0.26	0.42	0.39	0.38	0.40	0.09	0.18	1.00	1.00	1.00	1.00	1.00
γ_1	0.40	0.00	0.13	0.11	0.55	0.95	0.02	0.63	0.81	0.04	1.00	0.17	0.75
γ_2	0.47	0.20	0.15	0.07	0.69	0.82	0.06	1.00	0.99	0.28	0.85	0.11	1.00
γ_3	0.00	0.02	0.54	0.50	1.00	1.00	0.05	0.51	0.98	0.11	0.78	1.00	0.87
γ_4	0.59	0.36	0.14	0.21	0.45	0.41	0.06	0.09	0.42	0.18	0.39	0.06	0.42
γ_5	0.68	0.38	0.90	0.59	0.22	0.14	0.06	0.10	0.59	0.05	0.19	0.11	0.46
γ_6	0.56	0.28	0.93	0.70	0.20	0.29	0.03	0.08	0.76	0.17	0.51	0.36	0.72
γ_7	0.67	0.36	0.27	0.21	0.49	0.19	0.06	0.05	0.32	0.01	0.51	0.22	0.36
γ_8	0.53	0.13	0.02	0.11	0.60	0.83	0.05	0.17	0.80	0.13	0.11	0.83	0.82
γ_9	0.80	0.17	0.41	0.64	0.88	0.56	0.06	0.21	0.27	0.17	0.01	0.30	0.22
γ_{10}	0.54	0.47	0.47	0.79	0.44	0.17	1.00	0.20	0.71	0.22	0.13	0.37	0.78
γ_{11}	0.70	0.12	0.22	0.21	0.21	0.08	0.06	0.07	0.43	0.16	0.15	0.31	0.42
γ_{12}	0.46	1.00	0.76	0.76	0.47	0.01	0.06	0.27	0.58	1.00	0.00	0.02	0.49
γ_{13}	0.90	0.13	0.03	0.02	0.17	0.03	0.05	0.10	0.28	0.21	0.00	0.02	0.12
γ_{14}	0.83	0.08	0.00	0.07	0.35	0.82	0.06	0.10	0.32	0.52	0.00	0.04	0.37
γ_{15}	0.70	0.21	0.72	0.56	0.22	0.28	0.06	0.10	0.28	0.31	0.00	0.17	0.23
γ_{16}	0.82	0.03	0.51	0.36	0.33	0.08	0.06	0.19	0.24	0.32	0.00	0.01	0.11
γ_{17}	0.79	0.33	1.00	1.00	0.31	0.03	0.06	0.13	0.41	0.59	0.00	0.01	0.24
γ_{18}	0.81	0.21	0.62	0.48	0.33	0.63	0.00	0.23	0.08	0.17	0.00	0.00	0.05
γ_{19}	0.62	0.53	0.09	0.12	0.27	0.33	0.54	0.20	0.54	0.35	0.04	0.26	0.38
γ_{20}	0.79	0.03	0.26	0.64	0.88	0.57	0.03	0.16	0.27	0.46	0.00	0.12	0.29
γ_{21}	0.73	0.07	0.05	0.67	0.55	0.45	0.03	0.15	0.55	0.84	0.00	0.02	0.57
γ_{22}	0.13	0.02	0.42	0.21	0.04	0.06	0.05	0.17	0.47	0.07	0.52	0.02	0.44
γ_{23}	0.48	0.12	0.29	0.12	0.18	0.31	0.06	0.09	0.59	0.10	0.68	0.06	0.50
γ_{24}	0.50	0.09	0.57	0.36	0.00	0.22	0.06	0.01	0.47	0.03	0.71	0.02	0.50
γ_{25}	0.29	0.52	0.40	0.17	0.47	0.45	0.06	0.20	0.72	0.13	0.74	0.13	0.75
γ_{26}	0.88	0.42	0.69	0.62	0.33	0.50	0.05	0.19	0.16	0.00	0.00	0.00	0.06
γ_{27}	1.00	0.34	0.67	0.56	0.27	0.15	0.06	0.04	0.18	0.00	0.00	0.00	0.18
γ_{28}	0.95	0.00	0.60	0.55	0.27	0.21	0.06	0.18	0.20	0.00	0.00	0.00	0.08
γ_{29}	1.00	0.38	0.46	0.50	0.60	0.85	0.04	0.25	0.00	0.00	0.00	0.00	0.00
γ_{30}	0.61	0.03	0.34	0.20	0.33	0.41	0.03	0.13	0.46	0.12	0.29	0.05	0.33
γ_{31}	0.24	0.28	0.18	0.25	0.21	0.28	0.06	0.14	0.68	0.61	0.07	0.11	0.57

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_{32}	0.58	0.76	0.48	0.26	0.04	0.43	0.06	0.02	0.42	0.23	0.18	0.02	0.39
γ_{33}	0.79	0.24	0.60	0.34	0.37	0.73	0.00	0.10	0.80	0.18	0.03	0.48	0.38
γ_{34}	0.81	0.30	0.54	0.19	0.13	0.27	0.06	0.11	1.00	0.00	0.17	0.17	0.28
γ_{35}	0.98	0.39	0.36	0.41	0.41	0.52	0.04	0.25	0.45	0.11	0.00	0.06	0.06
γ_{36}	0.89	0.30	0.41	0.39	0.43	0.34	0.04	0.01	0.34	0.03	0.21	0.02	0.20

Step 4: Obtained absolute values by calculating deviation sequence from desires value using formula and prepared Table 4.

$$\Delta_{0(\gamma)=}|x_0(\gamma) - x_1(\gamma)| \qquad \textit{Eq. (6)}$$

Table 4. Deviation Sequence

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_0	0.00	0.26	0.42	0.39	0.38	0.40	0.09	0.18	1.00	1.00	1.00	1.00	1.00
γ_1	0.40	0.26	0.29	0.27	0.17	0.54	0.07	0.45	0.19	0.96	0.00	0.83	0.25
γ_2	0.47	0.05	0.28	0.32	0.31	0.42	0.03	0.82	0.01	0.72	0.15	0.89	0.00
γ_3	0.00	0.24	0.11	0.11	0.62	0.60	0.04	0.32	0.02	0.89	0.22	0.00	0.13
γ_4	0.59	0.11	0.28	0.18	0.07	0.01	0.03	0.10	0.58	0.82	0.61	0.94	0.58
γ_5	0.68	0.12	0.47	0.20	0.16	0.26	0.03	0.08	0.41	0.95	0.81	0.89	0.54
γ_6	0.56	0.02	0.51	0.31	0.18	0.11	0.06	0.10	0.24	0.83	0.49	0.64	0.28
γ_7	0.67	0.10	0.15	0.18	0.11	0.21	0.03	0.14	0.68	0.99	0.49	0.78	0.64
γ_8	0.53	0.13	0.40	0.27	0.22	0.43	0.03	0.01	0.20	0.87	0.89	0.17	0.18
γ_9	0.80	0.09	0.01	0.26	0.50	0.16	0.03	0.03	0.73	0.83	0.99	0.70	0.78
γ_{10}	0.54	0.21	0.04	0.40	0.06	0.23	0.91	0.02	0.29	0.78	0.87	0.63	0.22
γ_{11}	0.70	0.14	0.20	0.18	0.17	0.32	0.03	0.12	0.57	0.84	0.85	0.69	0.58
γ_{12}	0.46	0.74	0.34	0.37	0.08	0.39	0.03	0.09	0.42	0.00	1.00	0.98	0.51
γ_{13}	0.90	0.13	0.39	0.37	0.21	0.37	0.03	0.09	0.72	0.79	1.00	0.98	0.88
γ_{14}	0.83	0.17	0.42	0.32	0.03	0.42	0.03	0.09	0.68	0.48	1.00	0.96	0.63
γ_{15}	0.70	0.05	0.30	0.17	0.16	0.12	0.03	0.09	0.72	0.69	1.00	0.83	0.77
γ_{16}	0.82	0.23	0.08	0.03	0.05	0.32	0.03	0.01	0.76	0.68	1.00	0.99	0.89
γ_{17}	0.79	0.07	0.58	0.61	0.07	0.37	0.03	0.05	0.59	0.41	1.00	0.99	0.76
γ_{18}	0.81	0.05	0.20	0.09	0.05	0.23	0.09	0.05	0.92	0.83	1.00	1.00	0.95
γ_{19}	0.62	0.28	0.33	0.27	0.11	0.07	0.45	0.02	0.46	0.65	0.96	0.74	0.62
γ_{20}	0.79	0.23	0.16	0.26	0.50	0.17	0.06	0.02	0.73	0.54	1.00	0.88	0.71
γ_{21}	0.73	0.19	0.37	0.28	0.17	0.05	0.06	0.03	0.45	0.16	1.00	0.98	0.43
γ_{22}	0.13	0.23	0.00	0.18	0.34	0.34	0.04	0.02	0.53	0.93	0.48	0.98	0.56
γ_{23}	0.48	0.13	0.13	0.27	0.20	0.09	0.03	0.10	0.41	0.90	0.32	0.94	0.50
γ_{24}	0.50	0.17	0.15	0.03	0.38	0.18	0.03	0.17	0.53	0.97	0.29	0.98	0.50
γ_{25}	0.29	0.27	0.02	0.22	0.09	0.05	0.03	0.01	0.28	0.87	0.26	0.87	0.25
γ_{26}	0.88	0.16	0.27	0.23	0.05	0.10	0.03	0.00	0.84	1.00	1.00	1.00	0.94
γ_{27}	1.00	0.08	0.24	0.17	0.11	0.25	0.03	0.14	0.82	1.00	1.00	1.00	0.82
γ_{28}	0.95	0.26	0.18	0.16	0.11	0.19	0.03	0.01	0.80	1.00	1.00	1.00	0.92
γ_{29}	1.00	0.12	0.04	0.12	0.22	0.45	0.05	0.07	1.00	1.00	1.00	1.00	1.00
γ_{30}	0.61	0.23	0.09	0.18	0.05	0.01	0.06	0.06	0.54	0.88	0.71	0.95	0.67
γ_{31}	0.24	0.02	0.24	0.14	0.17	0.12	0.03	0.05	0.32	0.39	0.93	0.89	0.43
γ_{32}	0.58	0.50	0.06	0.13	0.34	0.03	0.03	0.16	0.58	0.77	0.82	0.98	0.61
γ_{33}	0.79	0.02	0.18	0.05	0.01	0.33	0.09	0.09	0.20	0.82	0.97	0.52	0.62
γ_{34}	0.81	0.04	0.12	0.19	0.25	0.14	0.03	0.07	0.00	1.00	0.83	0.83	0.72
γ_{35}	0.98	0.13	0.06	0.02	0.03	0.12	0.05	0.07	0.55	0.89	1.00	0.94	0.94
γ_{36}	0.89	0.04	0.02	0.01	0.05	0.06	0.05	0.18	0.66	0.97	0.79	0.98	0.80

Step 5: Established a co-efficient matrix of grey relation system using the formula:

$$\gamma[x_0^*(k), x_i^*(k)] = \frac{\Delta_{min} + \xi\Delta_{max}}{x_{0i}(k) + \xi\Delta_{max}}, \; 0 < \gamma[x_o^*(k), x_i^*(k)] \leq 1 \qquad \textit{Eq. (7)}$$

Table 5. Grey Relational Co-efficient

	χ_1	χ_2	χ_3	χ_4	χ_5	χ_6	χ_7	χ_8	χ_9	χ_{10}	χ_{11}	χ_{12}	χ_{13}
γ_0	0.00	0.26	0.42	0.39	0.38	0.40	0.09	0.18	1.00	1.00	1.00	1.00	1.00
γ_1	0.55	0.62	0.49	0.54	0.67	0.37	0.93	0.47	0.72	0.34	1.00	0.38	0.67
γ_2	0.52	0.92	0.51	0.50	0.51	0.43	1.00	0.33	0.97	0.41	0.77	0.36	1.00
γ_3	1.00	0.64	0.72	0.75	0.34	0.34	0.98	0.55	0.97	0.36	0.70	1.00	0.79
γ_4	0.46	0.82	0.50	0.64	0.83	1.00	1.00	0.80	0.46	0.38	0.45	0.35	0.46
γ_5	0.42	0.80	0.38	0.61	0.68	0.56	1.00	0.82	0.55	0.34	0.38	0.36	0.48
γ_6	0.47	1.00	0.36	0.51	0.65	0.75	0.94	0.80	0.68	0.38	0.50	0.44	0.64
γ_7	0.43	0.83	0.66	0.65	0.76	0.60	1.00	0.74	0.43	0.34	0.51	0.39	0.44
γ_8	0.49	0.77	0.42	0.54	0.60	0.42	0.99	0.96	0.72	0.37	0.36	0.74	0.74
γ_9	0.39	0.84	0.97	0.56	0.39	0.67	1.00	0.93	0.41	0.38	0.33	0.42	0.39
γ_{10}	0.48	0.67	0.87	0.44	0.85	0.59	0.35	0.95	0.63	0.39	0.36	0.44	0.69
γ_{11}	0.42	0.77	0.59	0.64	0.66	0.50	1.00	0.77	0.47	0.37	0.37	0.42	0.46
γ_{12}	0.52	0.35	0.46	0.46	0.81	0.45	1.00	0.81	0.54	1.00	0.33	0.34	0.50
γ_{13}	0.36	0.78	0.42	0.46	0.61	0.46	0.99	0.82	0.41	0.39	0.33	0.34	0.36
γ_{14}	0.38	0.72	0.41	0.50	0.92	0.43	1.00	0.81	0.42	0.51	0.33	0.34	0.44
γ_{15}	0.42	0.92	0.49	0.65	0.68	0.74	1.00	0.81	0.41	0.42	0.33	0.38	0.39
γ_{16}	0.38	0.65	0.77	0.94	0.88	0.50	1.00	0.97	0.40	0.42	0.33	0.34	0.36
γ_{17}	0.39	0.89	0.33	0.34	0.83	0.46	1.00	0.88	0.46	0.55	0.33	0.34	0.40
γ_{18}	0.38	0.93	0.59	0.78	0.87	0.59	0.90	0.88	0.35	0.38	0.33	0.33	0.35
γ_{19}	0.45	0.60	0.47	0.55	0.76	0.83	0.53	0.95	0.52	0.44	0.34	0.40	0.45
γ_{20}	0.39	0.65	0.64	0.56	0.39	0.65	0.95	0.94	0.41	0.48	0.33	0.36	0.41
γ_{21}	0.41	0.70	0.44	0.53	0.66	0.88	0.95	0.92	0.53	0.76	0.33	0.34	0.54
γ_{22}	0.79	0.64	1.00	0.65	0.49	0.48	0.98	0.95	0.48	0.35	0.51	0.34	0.47
γ_{23}	0.51	0.77	0.68	0.54	0.62	0.80	1.00	0.80	0.55	0.36	0.61	0.35	0.50
γ_{24}	0.50	0.72	0.67	0.94	0.46	0.65	1.00	0.70	0.49	0.34	0.63	0.34	0.50
γ_{25}	0.63	0.61	0.92	0.60	0.80	0.89	1.00	0.96	0.64	0.37	0.66	0.36	0.67
γ_{26}	0.36	0.74	0.52	0.58	0.88	0.78	0.99	1.00	0.37	0.33	0.33	0.33	0.35
γ_{27}	0.33	0.86	0.54	0.66	0.76	0.56	1.00	0.74	0.38	0.33	0.33	0.33	0.38
γ_{28}	0.34	0.62	0.62	0.67	0.76	0.63	1.00	0.97	0.39	0.33	0.33	0.33	0.35
γ_{29}	0.33	0.79	0.88	0.74	0.60	0.41	0.96	0.85	0.33	0.33	0.33	0.33	0.33
γ_{30}	0.45	0.65	0.77	0.64	0.87	0.99	0.94	0.87	0.48	0.36	0.41	0.34	0.43
γ_{31}	0.68	1.00	0.54	0.70	0.66	0.74	1.00	0.88	0.61	0.56	0.35	0.36	0.54
γ_{32}	0.46	0.45	0.84	0.71	0.49	0.93	1.00	0.71	0.46	0.39	0.38	0.34	0.45
γ_{33}	0.39	1.00	0.62	0.88	1.00	0.49	0.90	0.82	0.72	0.38	0.34	0.49	0.45
γ_{34}	0.38	0.94	0.71	0.63	0.57	0.71	1.00	0.84	1.00	0.33	0.38	0.38	0.41
γ_{35}	0.34	0.78	0.82	0.95	0.94	0.74	0.95	0.85	0.48	0.36	0.33	0.35	0.35
γ_{36}	0.36	0.95	0.95	1.00	0.89	0.87	0.97	0.69	0.43	0.34	0.39	0.34	0.38

Step 6: Calculated GRA grade using formula and arranged in ascending order Table 6:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta_k \gamma \; [x_0^*(k), x_i^*(k)] \qquad \textit{Eq. (8)}$$

where $\sum_{k=1}^{n} \beta_k$

Table 6. Grey Relational Grade (GRG)

S. No	Districts	Legends	GRG
1	Bahawalpur	γ_1	0.70
2	Bahawalnagar	γ_2	0.70

S. No	Districts	Legends	GRG
3	Rahim Yar Khan	γ_3	0.66
4	Dera Ghazi Khan	γ_4	0.66
5	Layyah	γ_5	0.65
6	Muzaffargarh	γ_6	0.64
7	Rajanpur	γ_7	0.63
8	Faisalabad	γ_8	0.63
9	Chiniot	γ_9	0.63
10	Jhang	γ_{10}	0.63
11	Toba Tek Singh	γ_{11}	0.63
12	Gujranwala	γ_{12}	0.62
13	Gujrat	γ_{13}	0.62
14	Hafizabad	γ_{14}	0.62
15	Mandi Baha-ud-Din	γ_{15}	0.61
16	Narowal	γ_{16}	0.61
17	Sialkot	γ_{17}	0.61
18	Lahore	γ_{18}	0.60
19	Kasur	γ_{19}	0.60
20	Nankana Sahib	γ_{20}	0.59
21	Sheikhupura	γ_{21}	0.59
22	Multan	γ_{22}	0.59
23	Khanewal	γ_{23}	0.59
24	Lodhran	γ_{24}	0.59
25	Vehari	γ_{25}	0.58
26	Rawalpindi	γ_{26}	0.58
27	Attock	γ_{27}	0.57
28	Chakwal	γ_{28}	0.57
29	Jhelum	γ_{29}	0.57
30	Sahiwal	γ_{30}	0.56
31	Okara	γ_{31}	0.56
32	Pakpattan	γ_{32}	0.56
33	Sargodha	γ_{33}	0.55
34	Bhakkar	γ_{34}	0.55
35	Khushab	γ_{35}	0.55
36	Mianwali	γ_{36}	0.52

Results and Discussion

The results showed that district Bahawalpur and Bahawalnagar have the highest grey relational grades, hence depict the best agricultural performance in Punjab, whereas district Mianwali has the lowest grey relational grade and accordingly least performance Table 6. The justification of results can be explored from inspecting the original data comparison of criterion variable of each district one by one can support the rationale of the results. Since the study uses equal weights for all the variables while during the application of GRA and Mianwali has clearly lesser use of the inputs and produces a lesser quantity of crops, therefore, it seems quite logical to attain a lower GRA relational grade as compared to rival districts that have high inputs and outputs. However, if the unequal weights are assigned to criterion variables, there may vary in results. Other reasons for this difference can be like ignoring the production of pulses, fruits, tobacco and vegetables that may again have an impact on the ranking. There is also an array of techniques of assessments like data envelopment analysis etc., that can also produce different results. The results of the study are comparable with some contemporary studies. Cao et al. (2017) have employed the water footprints (WF) technique to measure the use of water in rice crop and its impact on quality and water volume. Findings concluded that the quality of crop and usage of water volume differs accordingly to the availability of water drainage in districts. Kirby et al. (2017) examined the historical trend of crop production, water availability and food insecurity in Pakistan and projected them forward to 2050. Results showed that sown area, water usage and fodder for crops is increasing gradually. It also predicted that if this trend continues for a long time, it will lead to a doubling of groundwater usage. It further suggested that to secure already diminishing water resources; we need more dams, irrigation infrastructure, increasing crop yields, change in crop mix and import more or export less food. They recommended using more grounded water in the short to medium term. Rehman et al. (2017) examined the relation of rice output with water availability, production area and its effect on GDP. Regression analysis was employed, which revealed that area production and rice output have a positive, while water resources have a negative relation with the GDP of Pakistan. Ali et al. (2019) said that in India and Pakistan, agriculture is a major sector of the economy. They focus on improving the sustainability of the agricultural sector and understand that it is important to secure food resources for the local population as well as for other economies that rely on food import from these countries. Research demonstrated that they need to conserve water resources that are already declining. There are plenty of other studies investigating a multitude of perspectives on agriculture performance, importance and issues. However, contemporary research could not focus the output and input variables compositely like crops, threshers, mounters and reapers' contribution to agriculture produce (specifically at district level). Since it is a unique type of study, therefore, its results could not be compared with previous research. However, based on the statistics given in archival documents of the government of Pakistan (i.e. periodical publications of Punjab development statistics and the federal bureau of statistics), the results of the study are consistent but different in their nature and magnitude. Because it has taken not the only output of the agriculture sector of Punjab but also considered the input variables and evaluated their efficiencies to how much they contributed to agricultural production with given resources.

Concluding Remarks

The agriculture sector is the driving wheel of Pakistan's economy because Pakistan is heavily dependent on major crops. It accounts for approximately 19 % of GDP (GOP, 2017) and directly supports more than half of the total population. The province of Punjab is the most important agricultural constituent of Pakistan that is renowned for cotton, rice and wheat crops. This study was thus aimed to evaluate the districts of Punjab with respect to the use of resources and agricultural performance. For the evaluation, a wide range of multi-criteria decision-making techniques were considered but, since the purpose of the study was to evaluate and ultimately hierarchical districts on the basis of incomplete information of agricultural indicators, therefore, Grey Relational Analysis (GRA) was found to be appropriate. The analysis showed that district Bahawalpur and Bahawalnagar have the highest grey relational grades, hence depict the best agricultural performance in Punjab, whereas district Mianwali has the lowest grey relational grade and accordingly least performance. The results are plausible because they coincide with quantities of inputs and outputs. The districts having high quantities in all variables secured high grey relational grade and vice versa. It apparently seems simple because larger acceptable seemingly dominate; however, it is a bit complex due to some smaller acceptable. Other reasons include equal weights to variables in GRA and ignoring some of the crops as aforementioned. It is a seminal study that uses a unique methodology that has integrated thirteen different indicators of agricultural development in one mathematical model and assigned a distinctive composite grade to every district. It provides insights to policymakers to take corrective measures and/or adjust agriculture development policies. The results of the study can work as ingredients to design policies for sustainable food security. The study encompassed thirteen variables, including four major crops and nine non-crop indicators but, could not include fruits, vegetables, tobacco and pulses, which may be incorporated in future studies for sanctifying the results.

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Annexure A

Legends for Districts

Bahawalpur = γ-1, Bahawalnagar = γ-2, Rahimyarkhan = γ-3, Dera gazi khan = γ-4 , Layyah = γ-5, Muzafarabad = γ-6, Rajunpur = γ-7, Faislabad = γ-8, Chiniot = γ-9, Jhang = γ-10, Toba take singh = γ-11, Gujranwala = γ-12, Gujrat = γ-13, Hafizabad = γ-14, Mandi bahawdin = γ-15, Narowal = γ-16, Sialkot = γ-17, Lahore = γ-18, Kasur = γ-19, Nankanasahib = γ-20, Sheikhupura = γ-21, Multan = γ-22, Khanewal = γ-23, Lodhran = γ-24, Vehari = γ-25, Rawalpindi = γ-26, Attock = γ-27, Chakwal = γ-28, Jehlum = γ-29, Sahiwal = γ-30, Okara = γ-31, Pakptan = γ-32, Sargodha = γ-33, Bhakkar = γ-34, Khushab = γ-35, Mianwali = γ-36

Legends for Criterion Variables

Fertilizers= χ-1, Electric pumps = χ-2, Diesel pumps = χ-3, Tube wells = χ-4, Tractor = χ-5, Threshers χ-6, Harevester = χ-7, Mounter = χ-8, Total area sown = χ-9, Rice = χ-11, Cotton = χ-12, Sugarcane = χ-13, Wheat = χ-14.