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Agricultural machinery, irrigation systems and food grains: A symmetric novel analysis

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Abstract: Agriculture provides a living for a huge proportion of Pakistan's people, making it one of the country's most vital sectors. In this paper, we investigated the impact of irrigation sources (IS), agricultural machinery (AM), total food grains (TFG), and total cropped area (TCA) on the agriculture sector of Pakistan by using the annual data from 1991 to 2020. Using the symmetric (ARDL) approach, short-run and long-run estimations were employed to illustrate the connection between variables. A unidirectional linkage for the variables was checked through the VECM (Vector Error Correction Model) based Granger causality that is extracted. Further, FMOLS (Fully Modified Least Squares) and DOLS (Dyngamic Least Squares) techniques were also employed to encounter the robustness of the analysis. Results during the short-run and long-run show that the variables total irrigation sources (IS), agriculture machinery (AM), and total food grains (TFG) show the constructive impact on the agriculture sector of Pakistan, while the variable total cropped area (TCA) demonstrate the negative impact on the agriculture sector. Similarly, the consequences of VECM-based Granger causality show that all variables have unidirectional linkages. Furthermore, the findings of the FMOLS and DOLS explore that the variables irrigation sources (IS), agricultural machinery (AM), and total food grains (TFG) show the productive impact on the agriculture sector of Pakistan. But, unfortunately, the variable total cropped area (TCA) demonstrates the negative impact on the agriculture sector. No doubt, the agricultural sector significantly contributes to the growth of any economy. The government of Pakistan has to adopt new policies and plans that place a greater emphasis on the country's irrigation network and arable land in order to increase agricultural output.

Subjects: Agricultural Economics; Agriculture and Food

Keywords: Irrigation sources; crops production; food security; agricultural machinery; economic growth

1. Introduction

Agriculture is a major contributor to Pakistan's economy. Economic growth, food security, job creation, and rural poverty reduction all rely heavily on the economy's agricultural sector. It employs around 38.5% of the labor force and provides 19.2% of GDP. Farming provides a living for more than two-thirds to three-quarters of the population. Reduced arable land, climate change, water scarcity, and a widespread migration of people and employment from rural to urban areas all impede agricultural growth possibilities. As a consequence, new approaches to increasing agricultural productivity are required. Because of its wide forward and backward ties with secondary (industrial) and tertiary (services) sectors, it has the ability to considerably contribute to economic development (GOP, 2021). Climate change, fluctuations in temperature, water shortages, alterations in precipitation patterns, and rising input prices are all threatening the agricultural sector. The government is keeping a close check on staple crops and using intervention techniques to ensure a consistent supply of key food commodities at acceptable prices. The government's primary aim for rural development to stimulate economic growth is to increase farmers' access to credit and other types of financial services (GOP, 2020). Agriculture's contribution to emerging economies' GDP, employment rates, and food security all contribute considerably to poverty and hunger reduction. As such, it plays a major role in achieving the sustainable development goals set out by the Millennium Development Goals. To achieve this goal, agriculture is transitioning from more conventional techniques to more technologically sophisticated ones. Increases in agricultural production are unachievable unless cutting-edge techniques and inputs are used. Access to contemporary financial services is a critical component in the evolution of the agricultural industry, and agricultural finance plays a critical part in it. Therefore, agricultural financing is in high demand in order to boost agricultural productivity. Small farmers, on the other hand, may have difficulty obtaining finance from official sources due to a shortage of supply, a lack of collateral, or other considerations (Ajayi & Olutumise, 2018; Chandio et al., 2019; Jan et al., 2017).

Irrigation water has been subsidized in numerous economic sectors across the world because the true costs and benefits of irrigation development have been overestimated. Farmers who get government assistance for irrigation expansion may save money on output compared to those who do not. However, tax revenue from both social strata was collected to support irrigation system construction, resulting to improve economic disparities. Traditional agricultural tactics cannot reward farmers who do not instantly benefit from water projects and are at a relative cost disadvantage. Furthermore, labor-saving technology that increases productivity and crop quality may be very beneficial to farmers in newly irrigated areas (Athukorala & Wilson, 2017; Xu et al., 2017). In compared to other rich nations, Pakistan has a low agricultural production. Because of their small land holdings, out-dated agricultural methods, poor irrigation systems, and tardy adoption of new farming techniques, rural residents have less discretionary income and save less. As a result, farmers need financial aid from institutional banking organizations in order to adopt and apply increasingly complicated agricultural practices. It is almost hard to increase crop production without access to institutionalized agricultural loans. Because of the availability and accessibility of agricultural financing, rural people may buy farming supplies such as seeds, fertilizer, pesticides, and other instruments. To meet their credit needs, rural households rely on both formal and informal credit channels (Chandio et al., 2018; Rehman et al., 2022; Saqib et al., 2018). Climate change and atmospheric imbalances have resulted in an alarming increase in environmental hazards in recent years. Droughts and floods are only two examples of emerging threats that might harm the economy. Malaria and other infectious diseases are expanding, frozen lakes are melting, agricultural food production is declining, and the death rate is rising; all of this poses a danger to long-term prosperity. Because of the wide-ranging effects for water, human health, food and agricultural supply, natural resources, biodiversity, and natural ecosystems, the influence of growing economies on global warming ought to be examined (Benis & Ferrão, 2017; Luan et al., 2019).

The cornerstone of ecological sustainability is managing water resources in a manner that does not hurt or oversimplify ecosystems. Because of the necessity for harmony, there is a limit to how much water may be taken from the river and a limit to how much can be done to modify the river's natural flow pattern. The following limits are defined by the water demands of the ecosystem. If human exploitation or alteration extends beyond these limits, native species and valuable ecosystem goods and services will be lost over time (Richter et al., 2003). The success of agricultural sector in Pakistan is directly connected to the quantity of water available for irrigation. All kinds of

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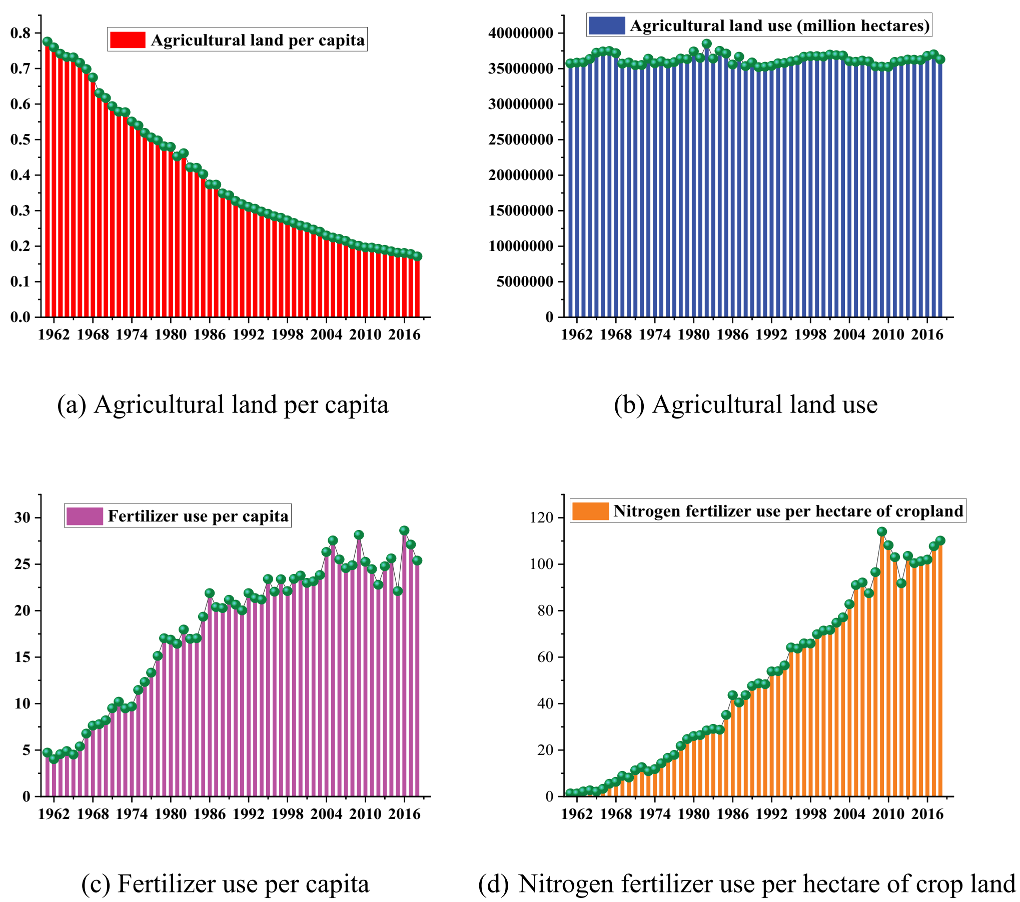
life need water to survive, yet freshwater is a limited resource that is becoming scarcer as its conflicting demands continue to rise. The Indus Valley Irrigation System, located in Pakistan, is the world's biggest continuous irrigation system. It includes the Indus River and its major tributaries and spans around 14.3 million hectares (35 million acres). There are three big reservoirs in the system (Tabela, Mangla, and Chashma), as well as 23 barrages/headwaters/siphons, 12 inter-river linkages, and 45 canal orders that together cover around (60,800) km to serve over (140,000) farmer operated watercourses. Irrigated agricultural land provides the country's economic backbone. Agriculture depends heavily on water, thus its availability and efficient use are inextricably related. Water is in greater demand, yet there are fewer ways to provide it or even sustain existing consumption levels (GOP, 2010, 2012).

The agricultural sector has a significant contribution in Pakistan's GDP. The industry is crucial to the country's economy and people survival. Cotton, wheat, rice, sugarcane, fruits, vegetables, etc., are the primary agricultural products. Pakistan has one of the world's most extensive networks of irrigation canals. More effective use of resources, especially land and water, is a critical issue for boosting agricultural output (Rehman et al., 2015). Figure 1 illustrates the time series historical trends of the agricultural land per capita, agricultural land use, fertilizer use per capita and nitrogen fertilizer use per hectare of cropland in Pakistan. Pakistan has put a lot of money into its water infrastructure because of how important it is to the country. A very filthy river, the Indus River naturally has a meandering development. The reason for this is that when silt accumulates on the river bed, the river seeks for lower ground and alters its route accordingly. Because of the destruction it wreaks on human communities, dikes are built all over the globe to channel and confine these rivers to their natural channels. The risk of flooding damage to embankments grows with time. A steady and consistent supply of food can only be produced with the help of a steady

Figure 1. Time series historical trends of the (a) agricultural land per capita, (b) agricultural land use, (c) fertilizer use per capita, and (d) nitrogen fertilizer use per hectare of cropland (1961–2018).



(a) Agricultural land per capita

(b) Agricultural land use

(c) Fertilizer use per capita

(d) Nitrogen fertilizer use per hectare of crop land supply of water and energy. This study adds to the existing body of knowledge on major agricultural and economic development aspects related with the agriculture sector. We investigated the effects of irrigation sources, agricultural machinery, total food grains, and total cropped area on Pakistan's agriculture sector using annual data spanning from 1991 to 2020. Three unit root testing was employed in the analysis to account for stationary effects. Using short-run and long-run estimations, the symmetric (ARDL) technique was utilized to highlight the connection between the variables. Using the VECM (Vector Error Correction Model), the derived Granger causality was examined for unidirectional relationships between the variables. The robustness of the study variables was also evaluated using the FMOLS and DOLS techniques.

2. Empirical existing literature

A continuous and steady supply of food can only be generated with the support of a consistent supply of water and energy. Another critical issue is protecting and maximizing floods, the majority of which are wasted as runoff. This helps decrease the negative impacts of large catastrophes and, by extension, the human suffering and economic losses they entail. Water conservation measures must be implemented quickly after natural catastrophes because to the ever-increasing needs of business, agriculture, and households.

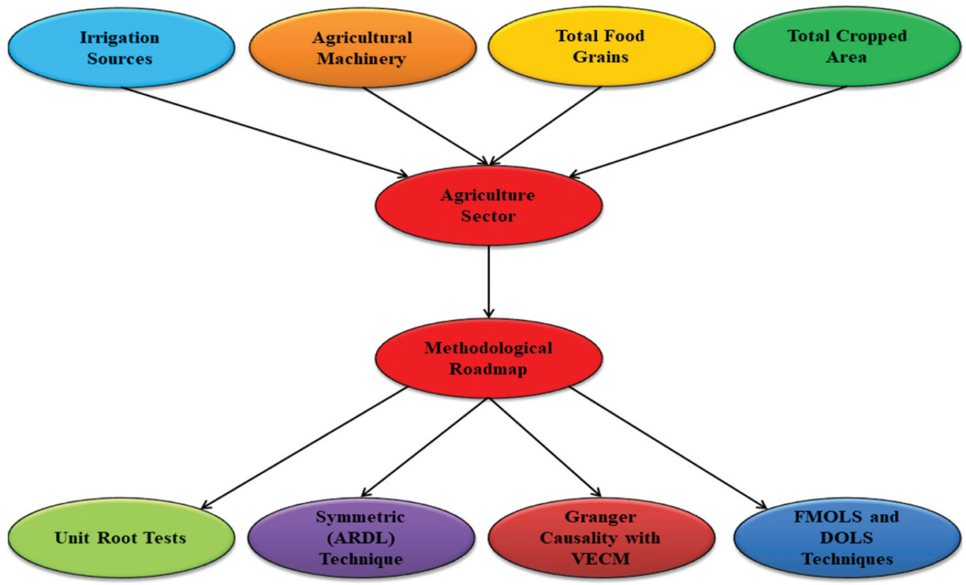
Groundwater is used to irrigate more than half of all agricultural land (Qureshi et al., 2010). Pakistan's economy is predominantly agricultural based, and farmers use around 94% of the country's surface and groundwater resources. This has resulted in an endless stream of issues for water authorities. Because agricultural, municipal, and industrial effluents have an influence on the health of freshwater bodies, there has been an increasing desire to enhance agricultural productivity while reducing stresses on the environment. Floods and droughts, on the other hand, lead certain places to acquire distinct characteristics. Temperature and precipitation changes have a significant impact on agriculture in Pakistan since most farming depends on rainwater gathering to maintain harvests. The land area of Pakistan is 96.9% soil, whereas just 3.1% is made up of reservoirs. Pakistan has a total of 23.04 million hectares of arable land, however only 10% is rain-fed due to the country's reliance on irrigation (GOP, 2017; Nasreen & Aqeel Ashraf, 2020; Qureshi et al., 2010). Growth in the national economy, the elimination of poverty, the maintenance of food security, and the improvement of the social and economic conditions of the people, particularly in rural areas, are all possible outcomes of progress in agriculture and related sub-sectors such as crops, livestock, fisheries, and forestry. Increasing productivity and adopting cutting-edge agricultural practices are two ways to do this. Foreign currency profits may be significantly boosted by the agriculture industry, which has the capability to not only fulfil local demand but also supply excess output for export. As an added downside, conventional farming and harvesting practices often result in poor yields per acre. Increasing output is an urgent need; hence the use of cutting-edge scientific procedures and machinery is essential. The farming community as a whole would benefit from a greater understanding of current agricultural methods. The efficiency and effectiveness of agricultural tasks are enhanced. Increases in agricultural output in Pakistan are being stymied by a shortage of high-quality seed varieties. A significant factor in high agricultural yields is the accessibility of improved seeds (Abid et al., 2014; Munir et al., 2021; Rehman et al., 2022; Zeb et al., 2022).

Continuous development in population and agricultural output creates heavy demands on water supplies. The agricultural sector consumes the vast majority of the country's water resources, while the residential and commercial sectors use very less. The economy is also confronting various natural and man-made calamities including floods, earthquakes, drought, landslides which also hinder agricultural development on a significant scale. Flood irrigation, which is still widely used in Pakistan, is an archaic practice that results in water loss of between 50 and 60 percent. The water is protected by a seepage irrigation system, and the plantation receives just how much water it needs. This is in contrast to the methods used in developed nations. Unfortunately, water shortage became a big concern in the economy, and after two dams, dam development has ceased (Awan & Aslam, 2015; Azam & Shafique, 2017; Khan et al., 2020; Rehman et al., 2016). Rain is the only consistent source of water for agricultural in many parts of the globe. Rainfall features alter on a daily, monthly, and annual basis, as well as regionally. Despite the abundance of meteorological data, the temporal and spatial variability of rainfall is poorly understood. Some seemingly basic problems have long perplexed planners. Basically, efficient rainfall is rain that can be put to good use. The timing, pace, and overall amount of precipitation received are not always ideal. It's probable that some of them will be ineffective, if not hazardous. The helpful component of rainfall is kept, while the remainder of the undesired component must be treated or passed on as soon as possible. Experts from various fields, and even those working in the same field, have varying views of what the phrase "effective rainfall" implies. Irrigation specialists believe the amount of precipitation that actually makes it into storage reservoirs, both directly and indirectly via surface runoff, to be an essential proportion (Adnan & Khan, 2009; Hassan & Hassan, 2017; Iqbal & Iqbal, 2015).

One of the most important aspects of agricultural development in underdeveloped economy is increasing reserve efficiency and optimizing the usage of agricultural inputs. Non-agricultural pressures on Pakistan's arable land and water supply are developing fast as a result of the country's growing population, rapid urbanization, and rapid industrialization. As a result, there is an increasing population and a decreasing quantity of cropland and irrigation water per person. Agriculture has become unaffordable in Pakistan as a result of the increasing cost of agricultural inputs such as fertilizers, herbicides, farm gear, and petrol. Farmers' worries about the future of agriculture and food production in Pakistan have been exacerbated by the influences of climatic change, such as higher average temperatures, altered rainfall patterns, and more frequent and severe floods (Chandio et al., 2017; Koondhar et al., 2018; Salam & Hameed, 2022). Conflicting needs for ever-greater quantities of irrigation water are straining today's water infrastructure, which is both aging and overburdened. As more and more river basins reach their maximum development potential, it will become more difficult to extend irrigation projects that rely on existing water supplies. Low crop yields can't be blamed on a lack of irrigation since supplies are insufficient. Crop water needs are not met in a timely manner due to mismatches between available water and seasonal fluctuations. The gap between availability and demand for water varies greatly by location and time of year. Traditionally, water resources have been administered only from a supply standpoint, with a focus placed on expanding irrigated regions through the building of additional dams. However, using existing resources efficiently to close the supply/demand mismatch has received little focus. Due to rising agricultural activity and decreased river flows, Pakistan's water demand has expanded at a far faster rate than availability. The tail ends of tributaries and streams also tend to have wider gaps during the summer growth season compared to the winter growing season. Due to water's central role in the agricultural process, the success of agricultural endeavours and their capacity to continue into the future are contingent on reliable access to sufficient supplies of this resource (Bhatti et al., 2009; Hassan et al., 2019; Lohano & Marri, 2020).

Despite water shortages and the worsening situation, farmers have not switched to more water-efficient irrigation techniques. Farmers today still use antiquated irrigation practices that cause a significant amount of water to be wasted. Many farms consist of only one or two families; therefore food for survival is in high demand. Traditional irrigation techniques are used due to a lack of finance and expertise in subsistence farming. Flood irrigation and furrow irrigation are only two examples of the most common types of traditional irrigation. Drip irrigation and sprinkler irrigation, both examples of pressurized irrigation technology, significantly reduce water use compared to more traditional approaches. Because of the increased demand for water, farmers often resort to drilling tube wells to tap into underground supplies when canal water is depleted. However, this causes water tables to drop, which places a strain on groundwater supplies. In addition, when the price of fuel and energy rises, the utilization of tube wells drives up production costs (Amin et al., 2014; Iqbal et al., 2005; Kahlown et al., 2007; Ul-Allah et al., 2014). Because improvements in irrigation efficiency may account for up to half of the increased water volume, some countries are investing in irrigation infrastructure to increase water flow and reduce delivery losses in present typical agricultural irrigation systems. Water policy is

Figure 2. Study mechanism and methodological roadmap.



becoming more important in the context of resource sustainability. Human behavior is the most significant impediment to successful water resource management, which is consistent with the current pattern of fast technological progress and delayed social advancement. Human actions have impacted the quantity and quality of freshwater resources. As a result, in order to handle complicated water management concerns, focused adaptations must be developed, adaptive capacity must be increased via updated water policies, and farmers must be educated and trained (Bekchanov et al., 2016; Iglesias & Garrote, 2015; Kahil et al., 2015).

3. Data sources and methods

In this study, the impact of irrigation sources (IS), agriculture machinery (AM), total food grain (TFG), total cropped area (TCA) and agriculture progress has been determined by utilizing the annual sequence data arrays from 1991 to 2020, and this data is taken from the Economic Survey of Pakistan and World Bank (World Development Indicators). Figure 2 demonstrates the mechanism of the study and methodological roadmap. Figure 3 exposes the key sources of irrigation in Pakistan (Canals, Wells and Tubewells). Further, Figure 4 is showing major food grains in Pakistan including wheat, rice, bajra, jowar, maize and barley production. Similarly, Figure 5 is demonstrating the area under these major crops.

3.1. Model specification

We have examined the impact of irrigation sources, agricultural machinery, total food grains and total cropped area to agriculture value added, and following model can be stated as:

$$AVA_t = \vartheta_0 + \vartheta_1 IS_t + \vartheta_2 AM_t + \vartheta_3 TFG_t + \vartheta_4 TCA_t + \varepsilon_t \quad (1)$$

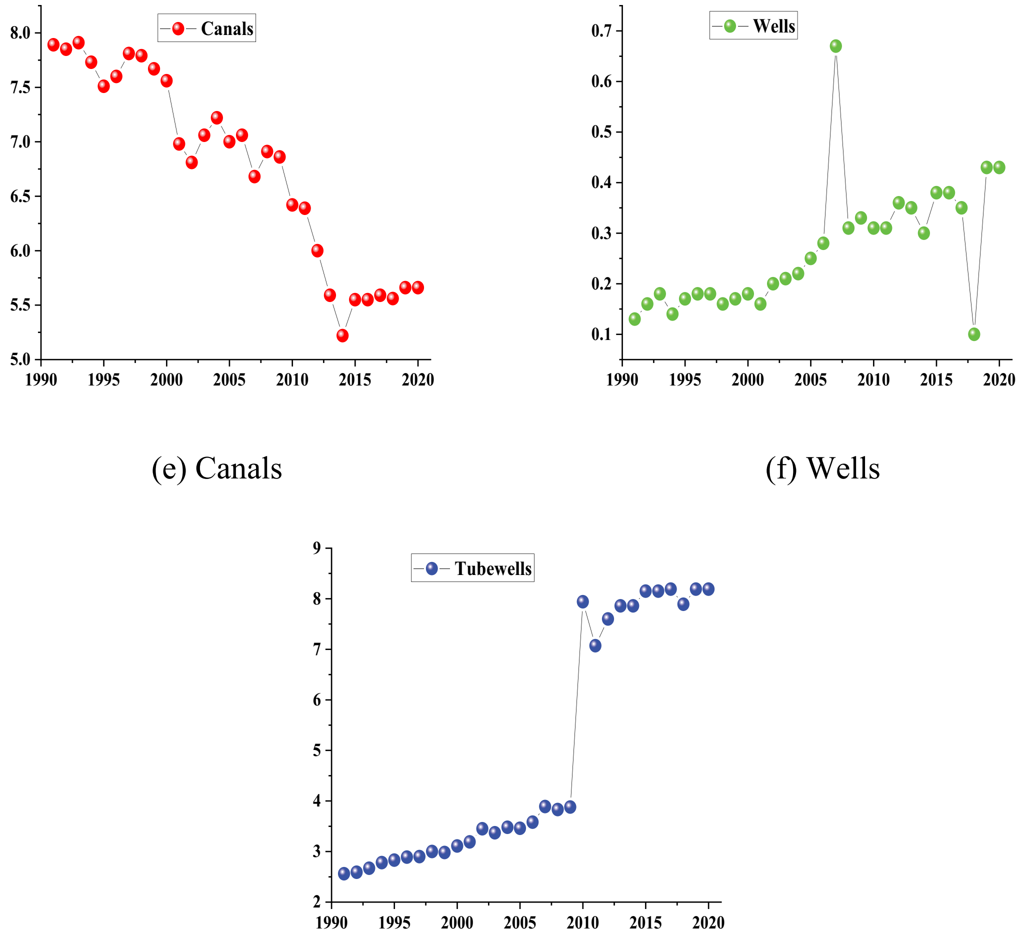
We can write Equation 1 further as:

$$LnAVA_t = \vartheta_0 + \vartheta_1 LnIS_t + \vartheta_2 LnAM_t + \vartheta_3 LnTFG_t + \vartheta_4 LnTCA_t + \varepsilon_t \quad (2)$$

where Equation 2 shows that, AVA_t = Agriculture value added; IS_t = Irrigation sources; AM_t = Agricultural machinery; TFG_t = Total food grains; TCA_t = Total cropped area, and t uncover the time measurement with the coefficients ϑ_1-ϑ_4 of model.

For the purpose of this investigation, we also employed the ARDL (Autoregressive Distributed Lag) technique created by Pesaran et al. (2001) to identify association between the variables under consideration. If the variables have been linked across time, an ARDL model may be used to analyse the data. In this case, the limit is irrelevant since the variable is held constant. When missing data causes

Figure 3. Irrigation sources in Pakistan (e) canals, (f) Wells, and (g) tubewells.



(e) Canals

(f) Wells

(g) Tubewells

faulty regressions, ARDL models provide a quick and effective fix. The focus of this research is on the long-run and short-run connections between agricultural value added and other factors. When looking for cointegration, it is necessary to use an ARDL model that includes an error correction feature, and the following is the specification of model with lags:

$$\Delta LnAVA_t = \lambda_0 + \sum_{l}^{l=1} \tau_l \Delta LnAVA_{t-l} + \sum_{l}^{l=0} \theta_l \Delta LnIS_{t-l} + \sum_{l}^{l=0} \varphi_l \Delta LnAM_{t-l} + \sum_{l}^{l=0} \eta_l \Delta LnTFG_{t-l} + \sum_{l}^{l=0} \psi_l \Delta LnTCA_{t-l} + \xi_1 LnAVA_{t-1} + \xi_2 LnIS_{t-1} + \xi_3 LnAM_{t-1} + \xi_4 LnTFG_{t-1} + \xi_5 LnTCA_{t-1} + \varepsilon_t \quad (3)$$

The lag order is indicated by the letter “l” in the equation (3). Similarly, the short-run dynamics between the variables may be investigated using error correction models demonstrated below as:

$$\Delta LnAVA_t = \lambda_0 + \sum_{l}^{l=1} \tau_l \Delta LnAVA_{t-l} + \sum_{l}^{l=0} \theta_l \Delta LnIS_{t-l} + \sum_{l}^{l=0} \varphi_l \Delta LnAM_{t-l} + \sum_{l}^{l=0} \eta_l \Delta LnTFG_{t-l} + \sum_{l}^{l=0} \psi_l \Delta LnTCA_{t-l} + \xi_1 LnAVA_{t-1} + \xi_2 LnIS_{t-1} + \xi_3 LnAM_{t-1} + \xi_4 LnTFG_{t-1} + \xi_5 LnTCA_{t-1} + ECM_{t-1} + \varepsilon_t \quad (4)$$

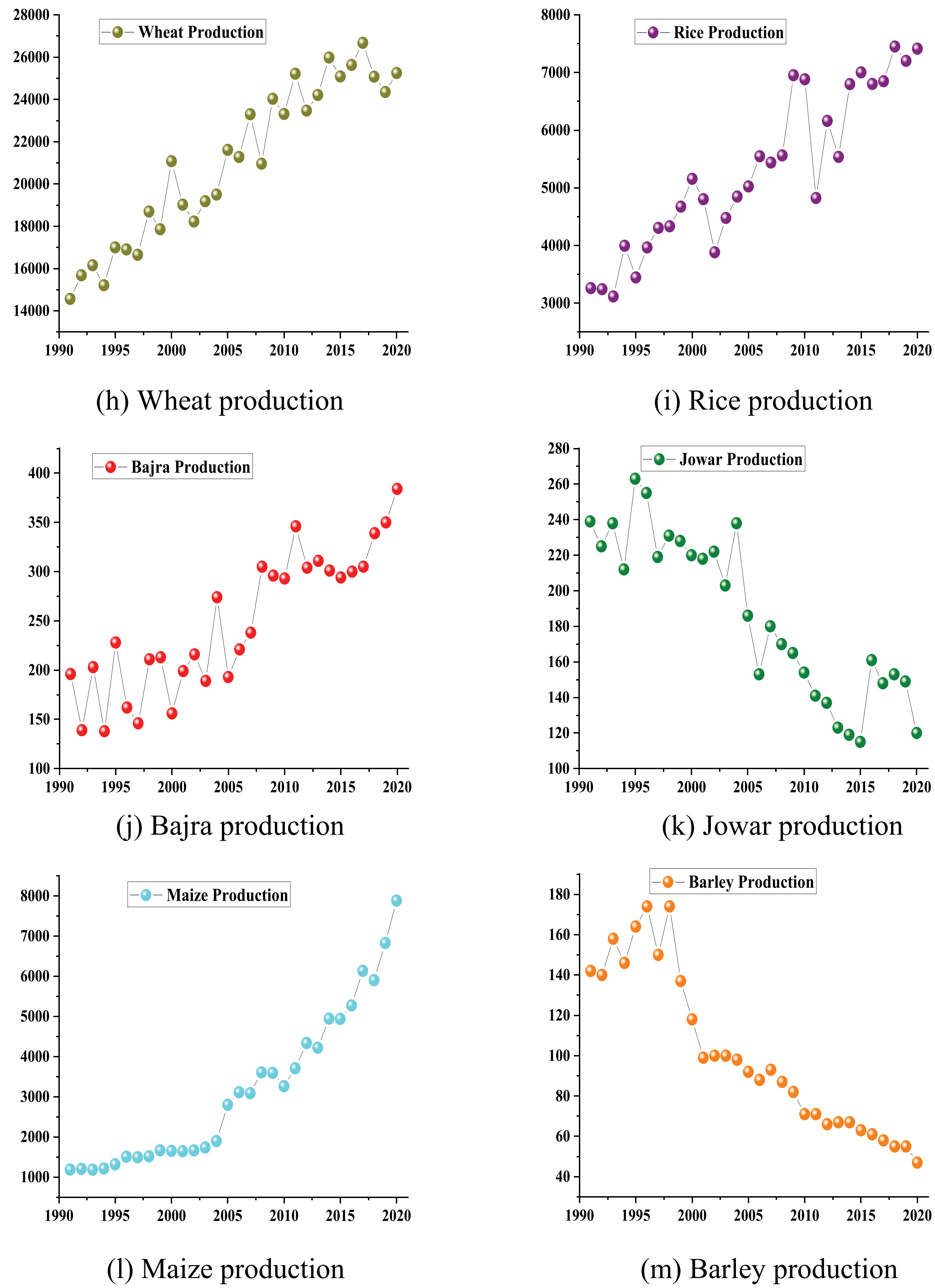


Figure 4. Crops production scenario (h) wheat production, (i) rice production, (j) bajra production, (k) jowar production, (l) maize production, and (m) barley production.

Equation 4 is showing short-run dynamics for the variables.

3.2. Granger causality with VECM (Vector Error Correction Model)

Long-run and short-run results show that this model's cointegration consistency has been tested using the ARDL model. Undefined correlations between variables were found in the findings. Further, the causal validation of vector error correction models may be used to identify the sources of variables by demonstrating their association with the observed values. For the purpose of organizing data and pinpointing their sources, Engle and Granger (1987) developed the vector

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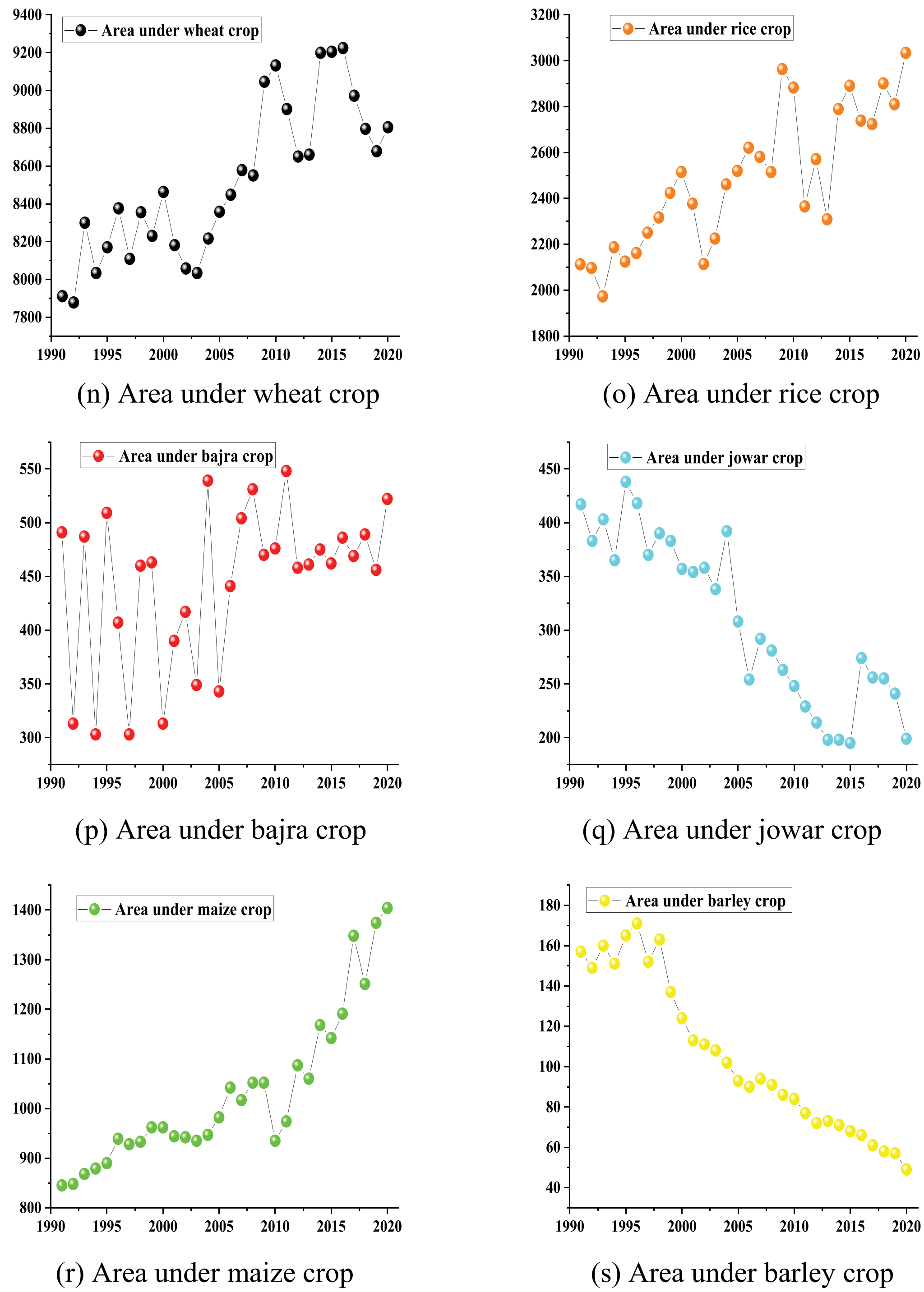
Figure 5. Area under grain crops (000 hectares) (n) area under wheat crop, (o) area under rice crop, (p) area under bajra crop, (q) area under jowar crop, (r) area under maize crop, and (s) area under barley crop.



error correction model (VECM). For quick evaluations, the error correction term (ECT) in consequence to short term will be employed if the specified model includes VECM variables or autoregressive distributed lag technique. VAR models will be used in short-run studies if the variables under examination are not co-integrated. The following is a description of the vector error correction model:

$$LnAVA_t = \vartheta_0 + \vartheta_1 LnIS_t + \vartheta_2 LnAM_t + \vartheta_3 LnTFG_t + \vartheta_4 LnTCA_t + \varepsilon_t \quad (5)$$

Where Δ designates the operator demonstrating the difference, β demonstrates the error term classification, and γ investigates the error term coefficient (ECT_{t-1}) in equation (5).

4. Empirical outcomes and discussion

Table 1 describes the summary analysis for the chosen parameters. According to the findings, the maximum large value for agricultural machinery is (11.178), while the minimum value for the variable total food grains is (9.882). Furthermore, the J-Bera figures for agriculture value added, irrigation sources, agricultural machinery, total food grains, and total cropped area are (2.678), (2.240), (2.305), (2.283), and (0.966), respectively. The correlation among the variables is shown in Table 2, and the findings expose that there is a link between all of the variables, including agriculture value added, irrigation sources, agricultural machinery, total food grains, and total cropped area.

4.1. Stationary test amid variables

Before beginning the regression analysis, make sure that the unit root tests of the variables are fulfilled using the DF-GLS, P-P, and KPSS tests (Elliot et al., 1996; Kwiatkowski et al., 1992; Phillips & Perron, 1988). Table 3 shows the outcome of the three tests. Many variables were shown to have long-term horizontal stability in this research, such as I(0). These variables become stationary after I(1). Both an I (0) series variable and an I(1) series variable are included in the model, representing the two different integration orders. Unit root testing yielded promising findings, so we moved on to the ARDL technique for our empirical investigation. Given that variables integration may be used in cointegration analysis by using ARDL. Surrogates lacking unit roots are not recognized here, hence the assumption is denied. Thus, we discard the hypothesis and accept the alternative that there is no unit root.

4.2. Lag length criteria

When deciding on an acceptable lag period, it should take into account the dynamic quality of the model. In the field of data analysis, the Akaike Information Criterion, often known as AIC, is frequently utilized to find the optimal order for lag data. Due to these constraints, we employed

Table 1. Summary statistics

	LnAVA	LnIS	LnAM	LnTFG	LnTCA
Mean	3.181	2.917	10.357	10.284	3.128
Median	3.181	2.934	10.456	10.313	3.127
Maximum	3.218	2.998	11.178	10.623	3.183
Minimum	3.138	2.818	9.218	9.882	3.078
Std. Dev.	0.026	0.049	0.574	0.231	0.029
Skewness	−0.059	−0.475	−0.525	−0.159	0.016
Kurtosis	1.540	2.058	2.139	1.686	2.121
Jarque-Bera	2.678	2.240	2.305	2.283	0.966
P-values	0.262	0.326	0.315	0.319	0.616

Table 2. Correlation analysis for the variables

	LnAVA	LnIS	LnAM	LnTFG	LnTCA
LnAVA	1.000	0.890	0.805	0.983	0.680
LnIS	0.890	1.000	0.892	0.899	0.768
LnAM	0.805	0.892	1.000	0.808	0.626
LnTFG	0.983	0.899	0.808	1.000	0.739
LnTCA	0.680	0.768	0.626	0.739	1.000

the AIC to govern suitable lag lengths for variables to include in the model. The findings are interpreted in Table 4.

4.3. Bounds testing to cointegration

The investigated results for cointegration testing are shown in Table 5. This analysis discovered that the upper and lower bounds of cointegration were 10%, 5%, 2.5% and 1% of the time, respectively, which is significant (F-statistic: 6.822). Integrals derived using bond tests reveal the technique's underlying long-term connections between variables. To further study cointegration among model variables, the Johansen cointegration approach (Johansen & Juselius, 1990) was used. The outcome of this procedure is shown in Table 6. Calculation of the lag frequency was performed using the Akaike information criterion (AIC). Using tracing and biggest eigenvalue tests, we can conclude that the null hypothesis that there is no cointegration equation in the model is not supported, at the 5% level of significance. Cointegration allows us to examine the long-term relationships between the variables of interest. As a result, it is possible to blend a few of them. Because of these consistent relationships, we may conclude that alternative hypothesis is erroneous.

Table 3. Unit root tests results

	LnAVA	LnIS	LnAM	LnTFG	LnTCA
DF-GLS unit root test at the level					
(T-stat. and P-values)	−1.487 (0.154)	−0.666 (0.512)	−1.369 (0.181)	−0.049 (0.961)	−1.908 (0.066)
DF-GLS unit root test at the first difference					
(T-stat. and P-values)	−4.773* (0.000)	−4.149* (0.000)	−1.241* (0.009)	−7.465* (0.000)	−6.228* (0.000)
P-P unit root test at the level					
(T-stat. and P-values)	−1.315 (0.608)	−2.781*** (0.073)	−1.608 (0.465)	−1.075 (0.711)	−2.302 (0.177)
P-P unit root test at the first difference					
(T-stat. and P-values)	−5.507* (0.000)	−6.885* (0.000)	−5.881* (0.000)	−7.771* (0.000)	−6.950* (0.000)
KPSS unit root test at the level					
(T-stat. and P-values)	0.692 * (0.000)	0.616* (0.000)	0.537* (0.000)	0.705* (0.000)	0.562* (0.000)
KPSS unit root test at the first difference					
(T-stat. and P-values)	0.196* (0.001)	0.500 (0.157)	0.500 (0.581)	0.350* (0.018)	0.281 (0.548)

Note: *, ***specifies 1% and 10% significance level.

Table 4. Lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	245.552	NA	1.26e-14	−17.818	−17.578	−17.747
1	323.507	121.264	2.58e-16	−21.741	−20.301*	−21.313
2	343.322	23.4841	4.69e-16	−21.357	−18.717	−20.572
3	391.011	38.857*	1.66e-16*	−23.037*	−19.198	−21.896*

Note: * specifies the lag order chosen by the criterion.

4.4. Symmetric analysis outcomes

Table 7 interprets the results of the symmetric investigation. Short-run dynamics reveal that the variables irrigation sources, agricultural machinery, and total food grains have coefficients (0.048), (0.001), and (0.038), respectively, with probability values (0.220), (0.594), and (0.015) indicating a constructive connection to Pakistan's agricultural sector. Unfortunately, total cropped area has a negative correlation with Pakistan's agriculture sector.

Moving on to the long-run dynamics findings, the variables irrigation sources, agricultural machinery, and total food grains have positive coefficients (0.123), (0.003), and (0.096), respectively, with probability values (0.227), (0.608), and (0.000) revealing a positive association with Pakistan's agricultural sector. The variable total cropped area negatively impacted the agricultural sector. In consequence to cropped area, about 22 million hectares are cultivated in Pakistan. Wheat took up 41.73 percent of the total planted area, followed by cotton (13.45 percent), rice (13.14 percent), maize (5.14 percent), and sugarcane (5.18 percent). These five basic crops account for about 78.64 percent of overall agricultural output. In addition, other crops occupied 21.36 percent of the land. In comparison to other developing countries, Pakistan's agricultural output and growth are lagging well behind the rest of the pack. Pakistan needs institutional finance to help rural families in making better use of fertilizers, insecticides, improved varieties, modern technology, and irrigation in order to raise agricultural output (GOP, 2019). Long-term inspection of total planted area revealed a detrimental relationship to Pakistan's agricultural economy. Climate change is increasing the economic losses caused by extreme weather. The average temperature

Table 5. Bounds testing for the cointegration

	Null Hypothesis: No levels relationship		
	Significance	**[I(0)]**	**[I(1)]**
F-statistic (6.822)	(10%)	(2.2)	(3.09)
K (4)	(5%)	(2.56)	(3.49)
	(2.5%)	(2.88)	(3.87)
	(1%)	(3.29)	(4.37)

Table 6. Johansen cointegration test

(Trace Test Statistics)			
Eigen-value	**T-Stat.**	**Prob.****	**Hypoth. No. of CE(s)**
0.614	60.183	0.229	(None)
0.438	33.493	0.529	(At most 1)
0.268	17.356	0.613	(At most 2)
0.197	8.606	0.403	(At most 3)
0.083	2.454	0.117	(At most 4)
(Maximum Eigenvalue Statistics)			
Eigen-value	**Max-Eigen Stat.**	**Prob.****	**Hypoth. No. of CE(s)**
0.614	26.689	0.280	(None)
0.438	16.136	0.654	(At most 1)
0.268	8.750	0.852	(At most 2)
0.197	6.152	0.593	(At most 3)
0.083	2.454	0.117	(At most 4)

Note: **denotes the Prob-values of MacKinnon-Haug-Michelis (1999).

Table 7. Symmetric analysis results

Short-run dynamics				
Variable	**Coefficient**	**Std. Error**	**t-Stat.**	**Prob.**
C	0.887*	0.234	3.778	0.001
LnAVA(−1)	−0.396*	0.106	−3.737	0.001
LnIS	0.048	0.038	1.259	0.220
LnAM	0.001	0.002	0.539	0.594
LnTFG	0.038*	0.014	2.615	0.015
LnTCA	−0.056	0.032	−1.709	0.100
CointEq(−1)	−0.396*	0.056	−7.059	0.000
Long-run dynamics				
LnIS	0.123	0.099	1.238	0.227
LnAM	0.003	0.006	0.519	0.608
LnTFG	0.096*	0.016	5.814	0.000
LnTCA	−0.141***	0.079	−1.787	0.087
C	2.240*	0.195	11.464	0.000
R^2 Log-likelihood Prob(F-stat.) S- criterion D-Watson stat.	(0.988) (129.921) (0.000) (−8.263) (2.055)	Adj-R^2 F-statistic Akaike info criterion Hannan-Quinn criter.		(0.986) (400.759) (−8.546) (−8.457)

Note: *, *** specifies 1% and 10% significance level.

and the normal rainfall pattern are both expected to rise. This suggests that the frequency and intensity of extreme weather and flooding are projected to increase in the next decades. The cost of rescue efforts, the number of victims, the destruction or loss of property, and the interruption of normal commercial activities will all have significant effects on the local community. For the government, it is difficult to provide enough compensation. In contrast, the environment has a significant impact on crop productivity, which has far-reaching effects on food security. Increased carbon in the atmosphere is thought to improve crops by acting as fertilizer, although this may have a net negative effect on developing economies. For example, food output in nations near the equator will decline owed to global warming (Barker et al., 2012; Droogers & Aerts, 2005; Spash, 2007).

Temperature, precipitation, and wind speed are all important factors in the protection of agricultural activities and yield. When global warming intensifies, the economics and food supply of underprivileged, rural people in emerging economies suffer greatly. Because agriculture is vital to ensuring food security and alleviating poverty, this presents a major threat to these two key global concerns (Arunrat et al., 2017; Cattiaux et al., 2012). If more water is utilized to irrigate the command area, then agricultural growth will slow down. The excessive extraction of water resources has been exacerbated by the loss in water supply brought about by the constant extension of irrigation command area in recent years. Ultimately, additional water regimes will be needed to fulfil the rising global water demand, and future projections imply that irrigated agricultural lands will rise to supply the food demands of a fast increasing population. Consequently, evaluating long-term shifts in agricultural land use, as reflected in shifts in crop patterns (crop planted area), is essential for enhancing water resource management decision-making (Arshad et al., 2019; FAO, 2009).

Utilization of groundwater is a major contributor to the potential degradation of groundwater ecosystems brought on by urbanization. The deterioration of groundwater in developing countries, especially in urban areas, is a direct result of the absence of good land use plans. Major cities in South Asian nations like Pakistan, India, and Bangladesh are under extreme strain on their water supplies due to population increase, drought, and heat waves. These patterns of rapid development are hastening the region's groundwater depletion. There is a direct correlation between the worth of life and the accessibility of water, both of which may be improved by the implementation of an efficient land use management system for urban growth in connection to groundwater. In light of this, it is important to evaluate how weather and land use affect our groundwater supplies (Mondal et al., 2021; Rajpar et al., 2019; Seo & Lee, 2016). Agricultural productivity is declining as a consequence of altering land-use patterns, which endangers both ecosystem health and human settlement. Agricultural productivity innovations have been proposed as a solution to these issues; they would help minimize yield disparities while promoting sustainable land use and economic growth. Family food insecurity has lessened and output has increased as a result of agricultural developments. However, underutilization and under adoption of productivity-enhancing technologies persist, notably in Pakistan (Senyolo et al., 2018; Tambo & Wünscher, 2018). The statistical values of R^2, F-stat. and D-Watson are (0.988), (400.759) and (2.055) respectively. Similarly, the stability tests findings are interpreted in Table 8 with F-stat (0.259), (0.301), (1.745) and p-values (0.773), (0.907), (0.200).

In addition, the cumulative sum and its square with having significance level of 5% are shown in Figure 6, which may be found here.

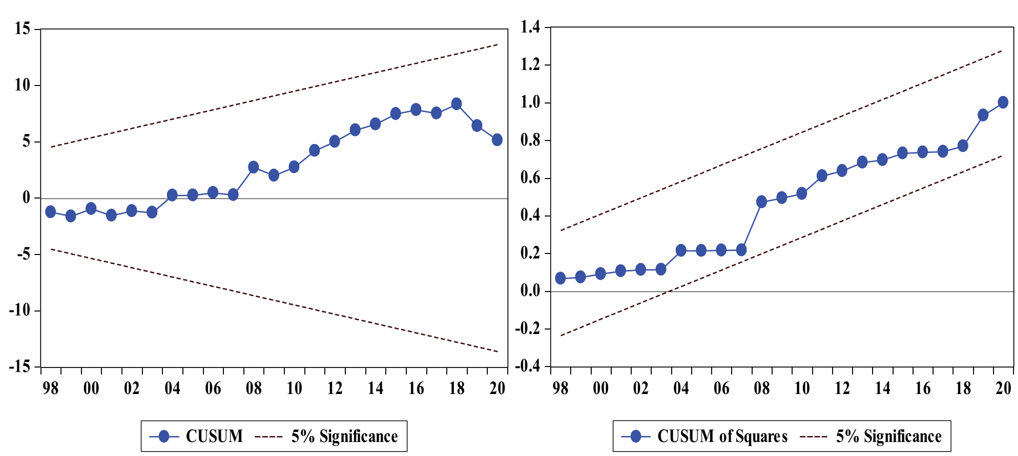
4.5. Cointegration regression analysis results

This study also used the FMOLS and DOLS approaches to look for the correlations amid variables, and the consequences are summarized in Table 9. Both FMOLS and DOLS studies indicated that irrigation sources, agricultural machinery, and total food grains have a productive correlation with Pakistan's agriculture sector, but total cropped area has an adversative relationship with Pakistan's agriculture sector.

Table 8. Stability tests outcomes

Tests	F-statistic	Prob.-values
Serial-Correlation test (Breusch-Godfrey)	0.259	0.773
Heteroskedasticity test (Harvey)	0.301	0.907
Ramsey-RESET Test	1.745	0.200

Figure 6. Graphical representation of (t) CUSUM, and (u) CUSUM of squares.



(t) CUSUM (u) CUSUM of Squares

https://doi.org/10.1080/23311932.2023.2279714

Table 9. Results of FMOLS and DOLS

(Fully Modified Least Squares)					(Dynamic Least Squares)			
Variables	**Coefficients**	**S-error**	**t-Stat.**	**Prob.**	**Coefficients**	**S-error**	**t-Stat.**	**Prob.**
LnIS	0.045	0.053	0.845	0.406	0.198	0.116	1.700	0.119
LnAM	0.000	0.003	0.240	0.812	0.009	0.006	1.548	0.152
LnTFG	0.115*	0.008	14.470	0.000	0.140*	0.008	16.652	0.000
LnTCA	−0.117*	0.043	−2.701	0.012	−0.007	0.058	−0.127	0.901
C	2.216*	0.105	20.960	0.000	2.232*	0.120	18.471	0.000
R^2	0.971	Mean dep. var		3.182	R^2	0.995	Mean dep. var	3.183
Adj-R^2	0.967	S.D. dep. Var		0.026	Adj-R^2	0.989	S.D. dep. var	0.025
S.E. of regression	0.004	Sum squared resid		0.000	S.E. of regression	0.002	Sum squared resid	7.020
Long-run variance	1.840				Long-run variance	4.940		

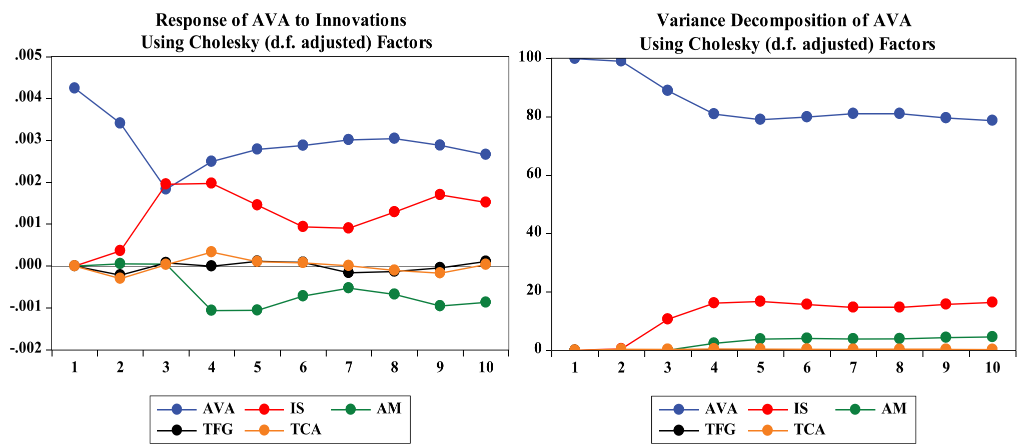
Note: * specifies 1% significance level.

Table 10. Outcomes of GC test under VECM

Dependent variables	Independent variables				
	ΔLnAVA	ΔLnIS	ΔLnAM	ΔLnTFG	ΔLnTCA
ΔLnAVA	—	−1.144	−24.849	−4.504	0.635***
ΔLnIS	−0.038	—	−2.585	−2.332	−0.454
ΔLnAM	0.004*	−0.034	—	0.126**	−0.001
ΔLnTFG	0.024**	−0.018	2.214	—	0.082***
ΔLnTCA	−0.001	0.243	2.693**	1.232	—

Note: *, **, *** specifies 1%, 5% and 10% significance level.

Figure 7. (V) impulse response function, and (w) variance decomposition analysis.



(v) Impulse response function (w) Variance decomposition analysis

4.6. *Granger causality test*

Adding cointegration to the outcomes of the Granger short-term causality test produces regressors the variable relationships used to investigate directional causality via regressors in Table 10. ARDL approach reveals long-term connections between variables under the investigation. Other indicators show a one-way connection between agriculture value added and other variables, such as irrigation sources, agricultural machinery, total food grains and total cropped area. These are known as short-term Granger linkages. Furthermore, Figure 7 demonstrate the impulse response function and variance decomposition analysis among all variables including irrigation sources, agricultural machinery, total food grains and total cropped area in Pakistan.

5. Conclusion and policy strategies

In this investigation, we examined the influence of irrigation sources, agricultural machinery, total food grains, and total cropped land on Pakistan's agriculture sector using yearly data ranging from 1991 to 2020. We conducted three unit root tests to ensure the stationary. The Symmetric (ARDL) approach was used to examine the relationship amid variables using short-run and long-run estimates. Using the VECM (Vector Error Correction Model) technique, the retrieved Granger causality was checked for unidirectional linkages for the variables. Furthermore, FMOLS and DOLS approaches were used to assess the robustness of the study variables. The short-run and long-run results suggest that the variables irrigation sources, agriculture machinery, and total food grains have a positive influence on Pakistan's agriculture sector, but the variable total cropped land has a negative impact. Similarly, the results of Granger causality based on VECM demonstrate that all variables exhibit unidirectional links. Furthermore, the FMOLS and DOLS outcome uncovered that the variables irrigation sources, agricultural machinery, and total food grains have a productive influence on Pakistan's agriculture industry. However, the total cropped area exposed the detrimental influence on agriculture sector. Agriculture, without a doubt, contributes significantly to economic success in any country. To increase agricultural output, the Pakistani government must devise new plans and policies focused on irrigation and cultivated land.

As a result, environmental concerns are handled in order to meet municipal, domestic, and industrial water needs while increasing agricultural production. Delta ecosystems and other bodies of freshwater need an understanding of constrained environmental fluxes as well as the capacity to replenish their water sources. As a consequence of all of this development, the amount of water available for agricultural use will be reduced. Access to safe drinking water is critical to human well-being on Earth. This lack of service has a negative influence on almost every aspect of the country's economy. Agriculture, as the single greatest consumer of freshwater, is strongly reliant on consistent and adequate water supplies to guarantee its sustained success and expansion. However, as populations rise and human activities and industrial expansion need more water, the amount of accessible water for irrigation will necessarily decrease. As a consequence, technological foresight should give comprehensive and long-term solutions to the challenges of water waste during floods and agricultural water management. To get the best results and boost the national economy, Pakistan's agricultural sector must be modernized and reformed. There is a pressing need to modernize and expand our agricultural industry via the use of cutting-edge technologies, the construction of new support structures, and the support of academic institutions devoted to agricultural research. Subsidized versions of modern farming equipment, insecticides, high-quality seed, and fertilizer should be made available to farmers. Investment in farms, expansion of trade, and efficient use of natural resources are only few of the initiatives used by the government to enhance the agricultural sector. Strengthening both the public and private sectors is necessary for Pakistan to upgrade its agriculture system. Mechanisation, well-organized irrigation systems, enhanced packaging and quality, larger dams, more agricultural land, and other initiatives would all benefit the agricultural sector. The deployment of cutting-edge agricultural technology should be prioritised by government policy. Large parcels of land were more productive than small ones in rural areas, contributing to the elimination of aristocracy. These effective measures may improve Pakistan's slowing economy.

5.1. Study limitations and future research directions

The influence of irrigation sources, agricultural machinery, total food grains, and total cropped area on Pakistan's agriculture sector is investigated in this research. However, this study has several limitations that may be used to guide future research efforts. Researchers are urged to use comparable econometric methodologies to an assortment of economies, spanning wide data ranges for various parameters in both developed and emerging countries, with the goal of shining light on agriculture sector development challenges across both developed and developing economies. More consistent and extensive findings may be gained by extending the existing study paradigm to incorporate other factors such as financial support for agricultural commodities, agricultural credit, climate change, and environmental sustainability.

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