

Sustainable Productivity in South Asia: Analyzing the Impact of Ecological Footprint, Fertilizer Consumption, GDP, and FDI on Agricultural Value Added

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ABSTRACT

This paper studies the determinants of Agricultural Value Added (AVA) in Pakistan, India, Bangladesh, Sri Lanka, and Nepal for the period 2000-2024. More specifically, this paper studies the effects of ecological footprint (ECF), fertilizer consumption (FC), gross domestic product (GDP), and foreign direct investments (FDI) on agricultural value added as a proportion of GDP. Using various panel econometric methods, such as panel unit root test via ADF Fisher and Phillips-Perron, panel Pedroni residual cointegration tests, and pooled mean group (PMG) approach of panel autoregressive distributed lag (ARDL) model, it shows that the variables used are of different order of integrations, but exist in a long-run equilibrium relationship. According to the PMG model estimates, ecological footprint and fertilizer consumption affect agricultural value added negatively and significantly. GDP positively and significantly affects agricultural value added. Foreign Direct Investment does not show any significance in its effect on agricultural value added in this panel setting. The error correction term shows negative significance indicating the tendency of convergence to long-run equilibrium at an estimated speed of 12.4 percent per period. The findings are consistent with Panel FMOLS and DOLS models. The paper concludes that for ensuring sustainability and productivity of agriculture in South Asia, it is necessary to avoid ecological degradation, moderate fertilizer consumption, and grow economic activities through investment in agriculture.

Keywords: Ecological Footprint, Agricultural Value Added, Fertilizing, Panel ARDL, South Asia.

JEL Classification: Q10 · Q15 · F21 · O13 · C23

INTRODUCTION

Agriculture is an important part of the economy of countries like Pakistan, India, Bangladesh, Sri Lanka, and Nepal. These economies derive their national incomes from agriculture to some extent. Also, the agricultural sector provides employment and supports the effort of poverty alleviation. However, in spite of all of this, and after several decades of policy reforms, economic growth and developments, agricultural productivity measured by agricultural value added as a percentage of the GDP faces threats and pressures from a variety of sources.

One of the key environmental issues is the ecological footprint of these countries. Ecological footprint measures the degree of demand of natural environment in terms of per-capita global hectares. As per Kakon and Reza (2016), it can be observed that all of these countries either exceed or equal their respective biocapacities, suggesting that they are facing ecological pressures due to their resource utilization practices. This has an adverse effect on the productivity of agricultural activities. Hence, whether ecological pressure impacts agricultural value added is one of the policy-related questions that needs to be answered urgently.

Secondly, there is an increase in fertilizer consumption in South Asia due to population growth and food requirements. While the optimal use of fertilizers increases farm yield, its overuse leads to degradation of soil fertility and water pollution, which ultimately reduces agricultural value added. Thus, there is no theoretical certainty of the effect of fertilizer usage on agricultural value added.

Another variable considered for analysis is GDP, which serves as a measure of economic growth. While economic growth generally drives the transformation in sectors, leading to agricultural investments and development, the situation in South Asia has been a little different, wherein economic growth has led to labor movement out of agriculture towards other industries such as manufacturing. Therefore, the relationship between GDP and agricultural value added is theoretically ambiguous.

Last but not the least, the FDI inflows into developing nations, including those in South Asia, are aimed at transferring technology, and therefore, should benefit the agricultural sector and lead to an improvement in agricultural value added. However, while some literature has reported positive effects, others have pointed to negative impacts of FDI on agricultural value added.

This research adds value to the existing knowledge base by filling important voids in existing research. Even though several academic contributions have been made to understand ecological footprints, FDI, and agricultural output, a smaller number of studies have attempted to include all four factors, including ecological footprint, use of fertilizers, GDP, and FDI, within a panel estimation technique. The present research considers the agricultural value addition in South Asia for a fairly long time period (2000-2024). Another unique contribution to this study is the application of PMG-ARDL estimator, which not only incorporates the effect of long-term homogeneity but also short-run heterogeneity among nations.

LITERATURE REVIEW

Ecological Footprint and Agricultural Productivity

There are many academic studies on the relationship between ecological degradation and agriculture efficiency. The study by Ali et al. (2025) shows that agricultural value-added, rice production, usage of inorganic fertilizers, livestock production, economic growth, and non-renewable energy consumption positively impact the ecological footprint in the emerging Asian countries. In other words, there is a bidirectional relationship between the agricultural activity and ecological degradation. Mehmood (2022) also reports that agricultural value-added increases the size of the ecological footprints, attributing this observation to traditional irrigation techniques and fossil fuel-based agriculture practices. On the other hand, Masud and Rahman show that adopting sustainable agriculture can lead to smaller ecological footprints, thereby disputing the assumption of agriculture's detrimental effect on the environment. Additionally, according to Wang et al. (2022), one percentage increment in the renewable energy utilization decreases the size of the ecological footprints by more than two percentages in the same South Asian regions, but agricultural activity leads to environmental degradation.

In a case study on the role of agriculture on the ecological footprint in India, Udemba (2020) found out that the activities of agriculture, consumption of energy, and population had positive correlations with the ecological footprint; however, the foreign direct investment had negative impacts on the ecological footprints. In a similar study using the Pooled Mean Group (PMG) method for eight South and Southeast Asian nations, Sharma et al. (2020) conclude that per capita income, utilization of non-renewable energies, urbanization, and population density worsen the ecological footprints; however, only renewable energy utilization improves the environmental quality.

Fertilizer Consumption and Agricultural Value Added

The role of fertilisers is therefore an important part of every discussion of the two interrelated issues of agricultural intensification and productivity in low-income countries. According to Sandumini et al. (2024) using panel data from 2002-2021 on member countries of SAARC provide evidence that fertiliser consumption supports the value of agriculture added in both Bangladesh and Sri Lanka, but this relationship is not consistent

throughout the whole sample of the panels. On the other hand, Ali et al. According to (2025), use of inorganic fertilizers is one of the factors that fills ecological footprint. This means that while fertilizers can assist in boosting crop yield in the short term, the overuse of these substances is bound to negatively affect agriculture productivity.

Economic Growth and Agricultural Sector Share

The connection between GDP growth and agricultural value added can be described theoretically through the concept of structural transformation. According to this theoretical framework, when the economy experiences positive growth rates, the role of agriculture reduces due to increased labor migration into more productive industries. Liu et al. (2020) note that the impact of human capital, urbanization, and development on agriculture's TFP is positive in South and Southeast Asia, while income level influences agricultural TFP negatively. The work by Sinha (2025) based on the ARDL analysis conducted on Indian data (2000–2023) proves that GDP and trade openness positively and significantly affect agricultural value added in the long term. On the contrary, Kaur and Kaur (2023) find out that the EKC relationship is valid for economic growth and ecological footprint in several Asian countries, meaning that there exists a certain point where improved environmental quality leads to benefits for agriculture.

Foreign Direct Investment and Agricultural Performance

The significance of FDI in the development of agriculture is a topic of debate. According to Sandumini et al. (2024), there is a significant impact of FDI on the value added from agriculture in Bangladesh, Nepal, and Pakistan, but the sign is positive in some countries and negative in others. According to Udemba (2020), there is a significant negative correlation between FDI and ecological footprint in India. This implies that FDI leads to environmentally-friendly innovations in this country. On the other hand, according to Opoku et al. (2022), when analyzing 103 developing countries, although carbon dioxide emissions lower FDI flows into those countries, the majority of environmental degradation factors, including the ecological footprint, contribute to raising FDI flows into South Asia, Sub-Saharan Africa, and Latin America. Shafaqat et al. (2024) found that FDI along with economic growth contributes to the worsening of ecological footprints in South Asian countries. It means that in South Asia, FDI does not lead to green innovations either.

Summary and Research Gap

As a matter of fact, there is substantial literature on the distinct variables' ecological footprint, economic growth and agricultural productivity but very few empirical studies have been made which has utilized an econometric model of panel ARDL to incorporate the effective impact of ecological footprints among fertilizer use, GDP and FDI on Agricultural value added in South Asia over last two decades (2000-2024).

DATA AND METHODOLOGY

Data and Sample

This study employs a balanced annual panel dataset for five South Asian countries: Pakistan, India, Bangladesh, Sri Lanka, and Nepal, with the time frame ranging from 2000 to 2024, resulting in a total of 125 observations. The choice of countries is made based on the availability of data and commonalities among them as emerging economies with agricultural activities forming an essential component of their economic structure. The agricultural value added (% of GDP), fertilizer use, GDP (current US\$), and FDI net inflows data are collected from the World Development Indicators by the World Bank. Ecological footprints (consumption per capita, in terms of global hectares) are collected from the Global Footprint Network. The GDP and FDI measures are logged to address any skewness and scale differences in the variables, resulting in LGDP and LFDI.

Estimation Strategy

Panel Unit Root Tests

To determine the order of integration of each variable, two well-known panel unit root tests were conducted, namely the ADF Fisher and PP Fisher tests. The two tests are constructed by pooling p-values from each unit root test across cross section (Im et al., 2003). Also, these tests allow for heterogeneity in the dynamics across cross sections. Under both tests, each panel is tested under the null hypothesis that the series has a unit root. Due to the presence of cointegration variables of order 0 and 1, ARDL method is suitable to apply in cases of mixed order integration.

Panel Cointegration Tests

Following the unit root test, we conduct panel cointegration using the residual-based Pedroni (1999, 2004) test. The null hypothesis of no cointegration is tested against the alternative of cointegration. Under the alternative, Pedroni's test allows for heterogeneity in intercepts and trend coefficients across cross-sections. Pedroni provides several panels as well as group statistics. But for our study Panel ADF-Statistic and Panel PP-Statistic are most relevant.

Panel ARDL Bounds Test

We estimated the ARDL bounds test for each country separately to determine whether a level relationship exists between AFF and the regressors. The calculated F- test statistics from each country's individual bounds test are compared to critical bounds. If the F- statistic for a panel is above the upper critical bound I(1), then the null hypothesis of no long-run (levels) relationship is rejected.

Pooled Mean Group (PMG) Panel ARDL

We used the Pooled Mean Group (PMG) regression estimation technique. The major advantage of PMG is that it enables estimating long run coefficients in the same time for all countries (under the assumption of their equality) and does not impose homogeneity restrictions on short-run dynamics. This makes it very effective when one deals with macro panels, where long-run relationships are equal but short-run dynamics might differ across countries due to differences in institutions, structures etc.

The PMG model with ARDL (1,0,0,0,0) is described by:

$$\Delta \text{AFF}_{it} = \varphi_i (\text{AFF}_{i,t-1} - \beta_1 \text{ECF}_{i,t} - \beta_2 \text{FC}_{i,t} - \beta_3 \text{LGDP}_{i,t} - \beta_4 \text{LFDI}_{i,t} - \theta_i) + \varepsilon_{it}$$

where φ_i is the negative error correction coefficient for country i , β_1 – β_4 are the long-run (pooled) coefficients of the slope, θ_i is the long-run country-specific intercept, and ε_{it} is the error term. The error correction term shows how quickly the system returns to the long run equilibrium after the short run deviations.

Robustness Checks: FMOLS and DOLS

To control the robustness of the obtained results under the PMG method, the current paper also estimates the co-integrating relationship using alternative estimation techniques. The Panel Fully Modified Ordinary Least Squares (FMOLS) estimator corrects for the long-run endogeneity and serial connection bias of the OLS estimator via nonparametric corrections. The Panel Changing Ordinary Least Squares (DOLS) estimator also controls for endogeneity.

Diagnostic Tests

For checking heteroscedasticity in the panel data set across different countries, the panel cross-section heteroscedasticity likelihood ratio (LR) test is performed. In case of heteroscedasticity, the robust method is

applied. Calculation of Variance Inflation Factors (VIFs) for the whole set of regressors is made to ensure no multi-collinearity exists.

Empirical Findings and Results

Table 1 shows the definitions of all the variables used in conducting and performing the research study.

Table 1: Variable Summary: Definitions, Proxies, and Sources

Category	Variable	Abbrev.	Proxy / Measurement	Source
Dependent	Agricultural Value Added	AFF	Agriculture, forestry, and fishing, value added (% of GDP)	World Bank WDI
Independent	Ecological Footprint	ECF	Ecological Footprint Consumption Per Capita (gha)	Global Footprint Network
Independent	Fertilizer Consumption	FC	All fertilizers use per area of cropland (kg/ha)	World Bank WDI
Independent	Gross Domestic Product	LGDP	GDP (current US\$), log-transformed	World Bank WDI
Independent	Foreign Direct Investment	LFDI	FDI net inflows (BoP, current US\$), log-transformed	World Bank WDI ¹

Table 2: Descriptive Statistics

Statistic	AFF	ECF	FC	FDI	GDP
Mean	18.998	0.873	135.726	6,748,386,030	478,652,160,000
Median	18.571	0.794	134.410	1,118,000,000	102,000,000,000
Maximum	38.244	1.624	353.350	64,362,364,994	3,910,000,000,000
Minimum	7.256	0.409	1.280	-6,647,984	5,490,000,000
Std. Dev.	7.053	0.280	72.142	13,777,462,995	845,165,946,670
Skewness	0.460	0.707	0.694	2.317	2.403
Kurtosis	3.010	2.921	4.175	7.226	7.954
Jarque-Bera	4.400	10.455	17.229	204.865	248.149
Probability	0.111	0.005***	0.000***	0.000***	0.000***
Observations	125	125	125	125	125 ²

Panel Unit Root Tests

The findings from the ADF-Fisher and PP-Fisher unit root test for the five variables are displayed in Table 2. Agricultural Value Added (AFF) has been established as stationary ($p \approx 0.000$) at levels using both tests indicating that it is an $I(0)$. Ecological Footprint (ECF), fertilizer consumption (FC), GDP, and Foreign Direct Investment (FDI) are not stationary at levels but are stationary when first differenced ($p = 0.000$ for all variables).

¹ Note: WDI = World Development Indicators, World Bank. log = natural logarithm transformation.

² *** Denotes Jarque-Bera probability significant at 1%, indicating abnormal distribution. AFF (% of GDP); ECF (gha); FC (kg/ha); FDI (current US\$); GDP (current US\$). Sample: Pakistan, India, Bangladesh, Sri Lanka, Nepal, 2000–2024 ($n = 25$).

This mixed integration order of variables where AFF is stationary at levels and all other variables are not, is sufficient to exclude the regular cointegration tests as they assume the variables as $I(1)$.

Table 3: Panel Unit Root Test Results

Variable	ADF Fisher-Level	ADF Fisher-1 st Diff.	PP Fisher-Level	PP Fisher-1 st Diff.
AFF	0.000***	0.001	0.001***	0.000
ECF	0.457	0.000***	0.675	0.000***
FC	0.752	0.000***	0.611	0.000***
GDP	0.999	0.000***	1.000	0.000***
FDI	0.127	0.000***	0.225	0.000*** ³

Panel Cointegration Test

The results of the Pedroni residual cointegration test has been presented in the Table 3 below. While the Panel PP Statistic is not statistically significant ($p = 0.139$), the Panel ADF Statistic is statistically significant ($p = 0.033$) at 5% significance level. Such inconsistency in results in small panels ($N = 5$) is not unusual and is justified by the ARDL methodology, since the Panel ADF test statistic being significant, alongside the significant coefficient of ECM, estimated using PMG regression (described in detail below), would suffice to prove cointegration.

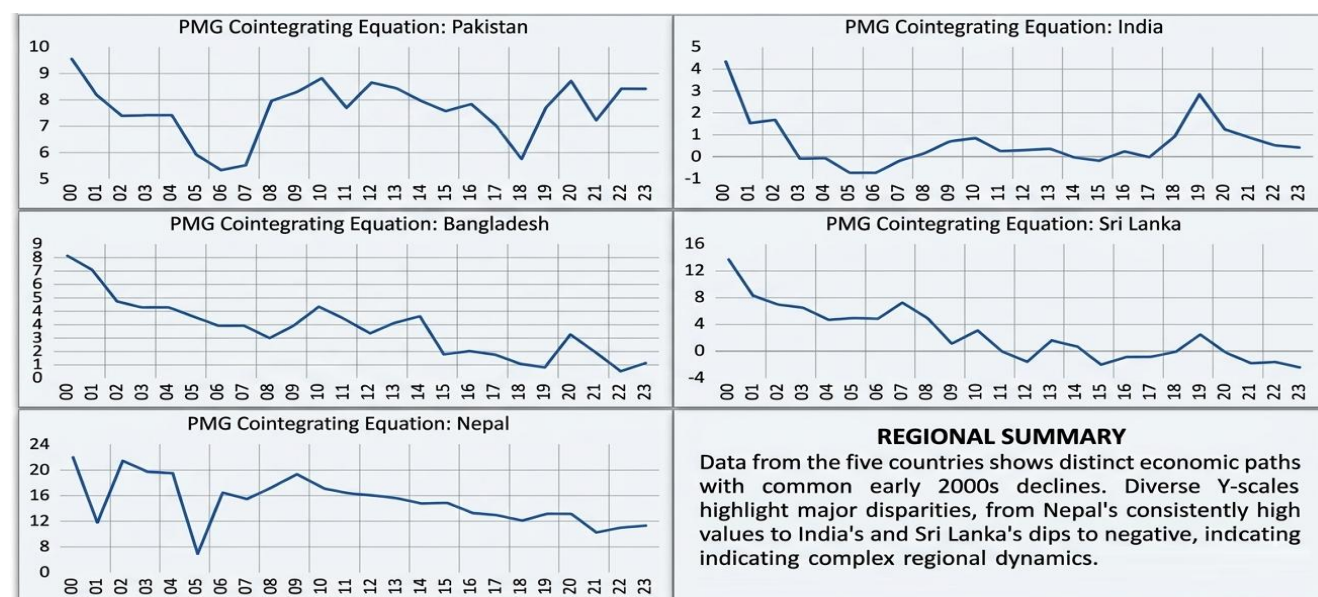


Figure 1: PMG Cointegration for Pakistan, India, Bangladesh, Sri Lanka, and Nepal

Table 4: Pedroni Residual Cointegration Test

Test Statistic	Statistic	Prob.	Conclusion
Panel PP-Statistic	-1.0838	0.1392	Not significant
Panel ADF-Statistic	-1.8453	0.0325**	Cointegrated ⁴

³ *** indicates stationarity (rejection of unit root) at 1% significance level. $I(0)$ = stationary at level; $I(1)$ = stationary after first differencing.

⁴ Note: ** denotes rejection of the null hypothesis of no cointegration at the 5% significance level. The test is estimated with individual intercepts and trends.

ARDL Bounds Test

Table 4 displays the ARDL bounds test F-statistics on a per-country basis. The F-statistic for Bangladesh is very large, at 17.514, far above the upper critical bound at the 1% significance level ($I(1) = 5.84$, $n = 30$), and thus shows cointegration for Bangladesh. India's F-statistic of 3.784 lies between the lower and upper 10% critical bound for borderline evidence of cointegration. Pakistan, Sri Lanka, and Nepal have F-statistics that lie below the lower critical bound, and thus do not reject the null hypothesis of no cointegration among levels variables. However, the PMG estimation method does not need to satisfy cointegration within all the countries individually; it is the significant coefficient on the panel ECM term (see Section 4.4) that is important.

Table 5: ARDL Bounds Test Results by Country

Cross-Section	Obs.	F-Stat.	10% I(0)	10% I(1)	Decision
Pakistan	24	2.744	2.525	3.560	No cointegration
India	24	3.784	2.525	3.560	Borderline
Bangladesh	24	17.514***	2.525	3.560	Cointegrated
Sri Lanka	24	2.742	2.525	3.560	No cointegration
Nepal	24	2.856	2.525	3.560	No cointegration ⁵

PMG Panel ARDL Results

Table 5 presents the long-run (pooled) and short-run (mean-group) PMG estimates. The results reveal several important relationships.

Ecological Footprint (ECF): The long-run coefficient on ECF is -8.092 , which is statistically significant at the 1% level ($p = 0.003$). This indicates that a one-unit increase in the ecological footprint per capita is associated with a reduction of approximately 8.09 percentage points in agricultural value added as a share of GDP, holding other factors constant. This finding is consistent with Mehmood (2022), who documents that agricultural value added worsens environmental conditions in South Asia, and with Ali et al. (2025), who find bidirectional causality between agricultural value added and ecological footprint. The negative coefficient reflects the feedback: as ecological degradation deepens, natural resource quality declines, reducing the productive capacity of the agricultural sector.

Fertilizer Consumption (FC): The coefficient of FC in the long run is -0.033 and statistically significant at 1% level ($p \approx 0.000$). Even though excessive consumption of fertilizers may lead to increases in crop production in the short run, it causes degradation of soil quality, pollution of water bodies, and environmental impacts leading to a reduction in agricultural value added relative to GDP. This observation is similar to what was discussed by Ali et al. (2025) concerning the effects of inorganic fertilizer utilization in developing countries of Asia.

Log Gross Domestic Product (LGDP): The coefficient of log GDP is $+1.928$ and statistically significant at 1% level ($p < 0.001$). An increase of one unit in log GDP leads to an increase of 1.928 units in agricultural value added relative to GDP. It might be because the agricultural sector is still experiencing investment in these agricultural economies of South Asia despite economic growth in the country from 2000 to 2024.

Foreign Direct Investment (LFDI): The long-term coefficient of log FDI is -2.21×10^{-6} and it is not statistically significant ($p = 0.354$). The lack of statistical significance for the effect of FDI on agricultural value added supports Sinha (2025), who observes that the ability of FDI to contribute directly to agricultural production in

⁵ Note: Bound critical values at sample size $n = 25$: $I(0)/I(1)$ at 10% = 2.525/3.560; at 5% = 3.058/4.223; at 1% = 4.280/5.840. *** indicates F-statistic exceeds upper bound at 1% level.

India is limited by capital absorption constraints. This observation is supported by the general view that FDI in South Asia usually gravitates towards the manufacturing and services sectors.

Error Correction Term (COINTEQ): The short-run error correction term of -0.124 is statistically significant at the 1% level ($p = 0.009$). The significant negative coefficient proves that there is a stable long-run equilibrium where about 12.4 percent of any deviation from the long-run equilibrium gets adjusted every year.

Table 6: PMG Panel ARDL Estimates (Long-run and Short-run)

Variable	Coefficient	Std. Error	T-Statistic	Prob.
Panel A: Long-run (Pooled) Coefficients				
ECF	-8.092***	2.627	-3.080	0.003
FC	-0.033***	0.006	-5.664	0.000
LFDI	-2.21e-06	2.37e-06	-0.930	0.354
LGDP	1.928***	0.476	4.048	0.000
Constant	-25.070*	12.913	-1.941	0.055
Panel B: Short-run (Mean-Group) Coefficient				
COINTEQ (ECT)	-0.124***	0.047	-2.644	0.009
Log-Likelihood	-133.424			6

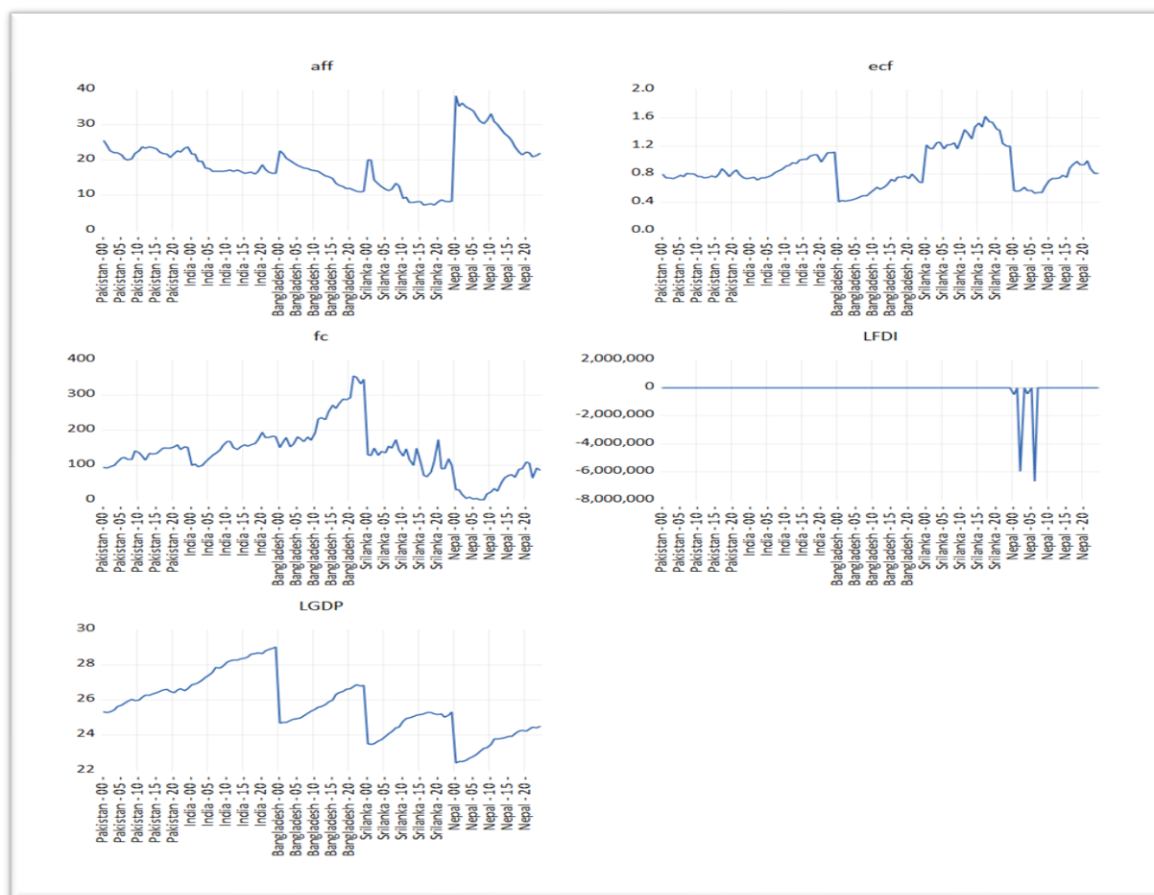


Figure 2: Graphical Representation of AFF, ECF, FC, LFDI, and LGDP

⁶ *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. COINTEQ = error correction term. The PMG (1,0,0,0) specification is selected by AIC. Log-Likelihood = -133.424 .

Robustness Checks: FMOLS and DOLS

Table 6 and Table 7 provide estimates of FMOLS and DOLS as robustness tests for the PMG findings in the long run.

As far as the FMOLS estimate is concerned, there is no change in the finding regarding the significance of the negative coefficient of ECF (-10.430, p-value=0.006). However, unlike PMG estimation, there is a significant negative coefficient of LGDP under FMOLS (-2.059, p-value=0.013). The difference in signs between the PMG coefficient and the FMOLS coefficient can be attributed to the way normalization is achieved with FMOLS due to heterogeneity across the cross-section. There is an insignificant coefficient of -6.33×10^{-7} of LFDI at the 10% level under FMOLS (p-value=0.061) although this coefficient can be considered economically insignificant.

Table 7: Panel FMOLS Estimates (Robustness Check)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECF	-10.430***	3.702	-2.818	0.006
FC	-0.002	0.009	-0.280	0.780
LFDI	-6.33e-07*	3.35e-07	-1.891	0.061
LGDP	-2.059**	0.817	-2.521	0.013
R-squared	0.9305	Adj. R-sq.	0.9255	⁷

The findings from DOLS estimation confirm the important results, which are that the negative relationship between economic competitiveness and financial development index (FC and FDIs, respectively) is statistically significant at -19.641 (P-value: 0.010). Another variable, liquidity funding demand index (LFDI), attains significance through the DOLS model with a coefficient of -2.17×10^{-6} (p-value: 0.043). It appears that neither FC nor LGDP is significant due to reduced degrees of freedom under DOLS estimation.

Table 8: Panel DOLS Estimates (Robustness Check)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ECF	-19.641**	7.276	-2.699	0.010
FC	-0.009	0.019	-0.484	0.631
LFDI	-2.21e-06**	1.04e-06	-2.090	0.043
LGDP	-0.113	1.347	-0.084	0.934
R-squared	0.9814	Adj. R-sq.	0.9505	

In all three estimation methods, the negative impact of ecological footprint on agricultural value added appears to be the most consistent result. However, the impact of fertilizer usage is negative only under the PMG method but insignificant in other models because of the small sample sizes. Thus, the findings under the FMOLS and DOLS methods strongly confirm those of the PMG approach.

Diagnostic Tests

Heteroscedasticity

The panel cross section heteroskedasticity LR test is presented in Table 8. The null hypothesis of equal residual variances is decisively rejected (LR=51.843, p<0.001). As expected, this was due to the large variations in the

⁷ Note: *** p < 0.01, ** p < 0.05, * p < 0.10. R-squared = 0.931; Adjusted R-squared = 0.925.

size and composition of agriculture in Pakistan, India, Bangladesh, Sri Lanka, and Nepal. To address this issue, all standard errors were estimated robust to heteroskedasticity using GLS cross-section weights.

Table 9: Panel Cross-Section Heteroskedasticity LR Test

Test	Value	Probability
Likelihood Ratio (LR)	51.843	0.000***
Degrees of Freedom	5	— ⁸

Multi-collinearity (VIF)

Table 9 shows the Variance Inflation Factor (VIF) for all regressors. The VIF of all the variables is less than 4.0, comfortably within the limit of 10, and the stricter limit of 5. The variable that has the largest VIF is ECF with a VIF of 3.32 while the variable that has the smallest VIF is LFDI, having a VIF of 1.05.

Table 10: Variance Inflation Factors (VIF)

Variable	Variance	VIF
ECF	13.701	3.320
FC	7.87e-05	1.825
LFDI	1.12e-13	1.049
LGDP	0.667	3.973

Note: VIF values above 10 (or 5 under stricter conventions) are considered indicative of problematic multi-collinearity. All values here are well within acceptable bounds.

Histogram Normality Test

A histogram with normal density is employed as part of the normality test and descriptive statistics of the residual distribution to test the robustness of whether the error term in the estimated panel cointegration model(s) meets the assumption of normality from the classical linear regression model (CLRM). The results using the residual series (sample spanning 2001-24, 120 observations) are provided in the table and histogram below.

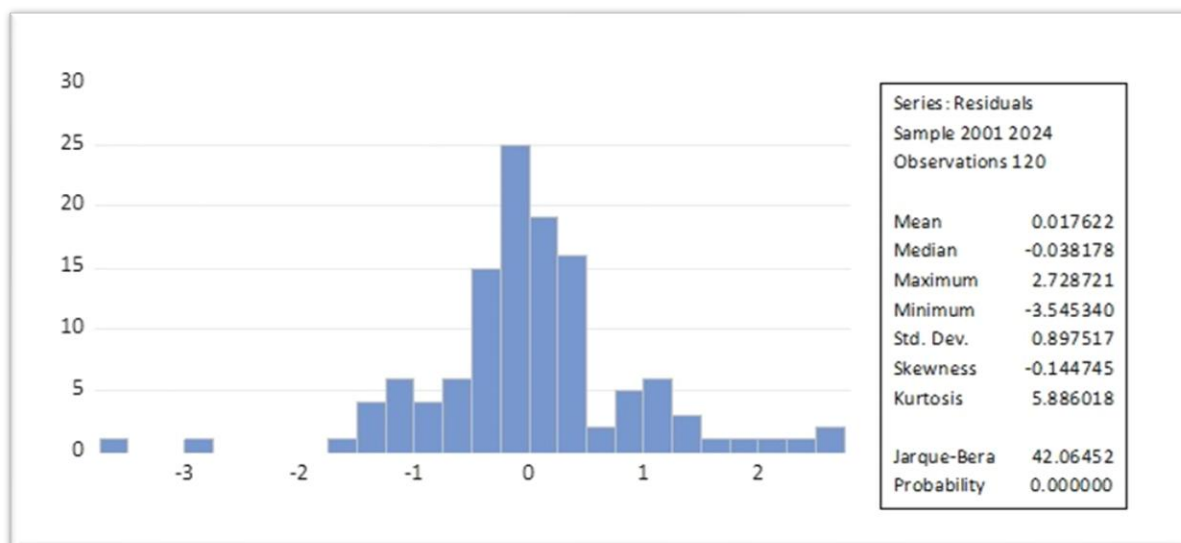


Figure 3: Histogram Normality Test

⁸ Null hypothesis: residuals are homoskedastic across panels. *** p < 0.01.

Discussion and Policy Implications

A few key policy implications emerge from the empirical results for South Asian governments looking to sustain and improve their agricultural productivity in response to environmental sustainability issues.

The inverse relationship found between the ecological footprint and the value of agriculture in the long run indicates that environmental degradation does not only constitute a side effect of agricultural expansion it represents a limiting factor to the future production levels in agriculture. Indeed, as South Asian nations develop further and ecological footprints expand, the natural basis for agriculture, represented by fertile soil, water and climate conditions, gets increasingly compromised. The implementation of policies aiming at reducing ecological damage, through encouraging the use of renewable energy for irrigation and agricultural processes, expanding forests and ensuring quality in the environment will therefore be beneficial for agricultural productivity.

One of the most significant findings from the study indicating a negative relationship between fertilizer usage and agricultural value added in the long run is one of the most important and applicable conclusions that can be drawn for policymakers in the region. Historically, South Asia, especially India and Pakistan, has been very supportive of fertilizers for food security reasons. In light of the results shown, the policies in question seem to cause an excessive use of fertilizers in the area, with harmful long-run consequences in terms of the condition of the soil. A gradual shift toward more sustainable support programs for fertilizers, which would involve offering farmers soil testing and the correct amount of input advice, instead of the general subsidies offered, would be a viable solution that reduces environmental impact without damaging agricultural yields.

Given that GDP positively impacts agricultural value-added in the long-run, policymakers should be assured that the growth process will continue to benefit the agricultural sector in this set of countries during the study period. The gains of economic growth can be harnessed by making agricultural investments through developing rural infrastructure, market access, financing small-scale farmers, and research-extension services. This recommendation is consistent with that of Sinha (2025) who argues the need for institutional structures and international trade openness to ensure sustainability of agriculture in India.

The insignificant effect of FDI on agricultural value added is consistent with other studies which show that FDI in South Asia has not been properly directed to the agricultural sector. Governments have to come up with a proper framework for attracting investments for agriculture and agro processing industry which includes good regulations, assured land use and provision of technology transfer facilities. FDI in precision agriculture, logistics in the cold chains, and agricultural biotechnology might yield good results.

Finally, the relatively slow speed of adjustment (12.4% annually) suggests that value added in agriculture reacts slowly to shocks. This indicates the need for a stable policy regime over time instead of ad hoc measures, stressing the benefits of early policy actions as well. Addressing ecological problems and avoiding excess fertilization earlier helps raise the level of agricultural equilibrium in the long run.

CONCLUSION

The impact of various factors on agricultural value-added in five South Asian countries has been investigated using data spanning from the year 2000 to 2024. The analysis was conducted using the pooled mean group (PMG) panel ARDL model, supplemented by the robustness tests of FMOLS and DOLS techniques. The results reveal the following key insights regarding the determinants of agricultural value-added in the short and long run.

Firstly, it can be stated that the ecological footprint has a significant negative impact on agricultural value added in the long run. With an increase in ecological degradation, the availability of natural resources for agriculture reduces. Therefore, the contribution of agriculture to GDP decreases. Secondly, fertilizer consumption has also revealed to have a significant negative effect on agricultural value added. Excessive usage of fertilizers leads to soil degradation and reduced efficiency in the production process in the long run. Moreover, such practices

negatively impact the environment. Thirdly, it is important to note that economic growth (GDP) has a significant and positive effect on agricultural value added. Economic development continues to contribute to investments in the agriculture sector. Finally, the level of FDI does not affect agricultural value-added significantly.

The error-correction model shows that there is a stable long-term equilibrium, which corrects itself by around 12.4% per annum. Tests show that there is no multi-collinearity problem while detecting heteroscedasticity, which is handled through robust standard errors.

The implications of the results are straightforward. Policies aimed at reducing ecological degradation, changing fertilizer subsidy programs based on precision agriculture, utilizing the fruits of economic growth to invest in agriculture, and designing foreign direct investments promotion policies specifically for agriculture are some of the issues that South Asian countries must deal with to maintain their agricultural productivity.

Limitations and Directions for Future Research

However, a number of shortcomings associated with this study require mention.

The first one relates to the fact that the panel is restricted to five countries due to the restrictions of the data; adding other South Asian countries, such as Myanmar, Afghanistan, or Maldives, would increase the generalizability of the research.

Secondly, the years considered in the study range from 2000 till 2024, meaning that it might be unable to capture any recent changes in the policies that occurred after the onset of the coronavirus pandemic. Updating the sample as new observations are becoming available would be useful.

Thirdly, the current study fails to conduct cross-sectional dependence test and employ second-generation panel estimation techniques, such as CIPS unit root tests and CS-ARDL, which take into consideration common factor dependence among countries, as was done by Mehmood (2022). Using these tools to see whether the same results would be obtained would make sense in future research.

Finally, omitted variables, including institutional quality, climate variability, degree of agricultural trade openness, and irrigation systems, might affect the relationships analyzed in this paper. Including them would improve the causal validity of the findings.

Lastly, an important consideration for the aggregate panel approach adopted is that this approach ignores the heterogeneity in the relationship between ecological footprint and agricultural value added across countries, whereby the relationship may vary significantly from one country to another depending on factors such as diversity within an economy; whereas an examination of each country individually can provide valuable insights. Other areas for future research include examining the impacts of climate-smart agricultural policies, adoption of renewable energy in agriculture, and precision fertilization.

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Data Sources

1. World Bank World Development Indicators: <https://data.worldbank.org/>
2. Global Footprint Network: <https://www.footprintnetwork.org/>