Identifying the Relationship between Environmental Degradation and Economic Growth: A Focus on the Environmental Impacts of Rice Cultivation in the Top Ten Rice-Producing Countries

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Abstract

In this study, the environmental Kuznets curve (EKC) was tested for the first time in the agriculture sector of ten rice-producing countries namely China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Japan, the Philippines, and Brazil, using panel data from 1995 to 2018. Once the EKC was tested at the aggregate level, the results were compared with those of the model disaggregated by the agriculture sector. We examined the relationship between environmental degradation (i.e., PM2.5, PM10, and CH4 emitted during rice cultivation processes) and economic growth, as well as agricultural growth, alongside other explanatory variables. Employing panel econometrics techniques, there is evidence of the EKC with an inverted U-shaped at both aggregate and disaggregate models. Including additional environmental explanatory variables such as urbanization, population density, and financial development, our results are robust and significant. The validity of the inverted U-shaped EKC suggests that compact environmental legislation, efficient energy use, and green technologies can reduce emissions as the economy and agriculture sectors expand

1. Introduction

The greenhouse effect plays a crucial role in the continued survival of life on Earth. However, human activities such as agriculture, industrialization, and urbanization have damaged the natural environment and increased environmental degradation (henceforth ED) (Selcuk, Gormus, & Guven, 2021). Thus, ED, pollution, global warming, and climate change have received considerable attention from academics, researchers, policymakers, and energy economists over the past several decades (Ali, Ashraf, Bashir, & Cui, 2017; Allard, Takman, Uddin, & Ahmed, 2018; Chien et al., 2021). In order to reduce poverty and speed up economic growth, developing nations need to boost production and other economic activities that raise living standards. Promoting these activities causes an increase in greenhouse gas emissions that have severe consequences for the global climate (Akram, 2013). Economic growth in developing countries is more carbon intensive than economic growth in developed countries because of technological development and innovation.

According to Kuznets' seminal 1955 work, there is an inverted U-shaped relationship between income and income inequality. This relationship has been reinterpreted as an Environmental Kuznets Curve (EKC) since 1990 (Ullah & Khan, 2020). Since then, the EKC hypothesis has been the predominant explanation for the relationship between economic growth and ED. According to the EKC hypothesis, economic growth and ED are inversely related (Demissew Beyene & Kotosz, 2020). It hypothesizes that, high resource consumption during the initial stages of economic development inevitably reduces bio capacity and increases the ecological footprint, resulting in a rapid increase in pollution levels. Upon reaching a certain income level, however, the trend reverses, resulting in an improvement in the environment.

Several empirical studies investigating the validity of EKC using samples from different countries observed an inverted U-shaped EKC curve (Dogan, Taspinar, & Gokmenoglu, 2019; Panayotou, 1997; Sarkodie & Ozturk, 2020; Sarkodie & Strezov, 2019). Moreover, other studies have provided a U-shaped

EKC (Ozcan, 2013; Ozturk & Al-Mulali, 2015). Although agriculture is recognized as a driver of economic growth, particularly in emerging countries, some scholars are concerned about its potential impact on environmental quality (Gollin, Parente, & Rogerson, 2002; Lewis, 1954). Increased agricultural production has a significant effect on air pollution as it increases greenhouse gases such as methane and nitrous oxide (Cetin, Bakirtas, & Yildiz, 2022). Various empirical studies have examined the possibility of an environmental Kuznets curve in the agriculture industry (Ali et al., 2017; Cetin et al., 2022; Ntim-Amo et al., 2021; Ogundari, Ademuwagun, & Ajao, 2017; Ullah & Khan, 2020).

Extreme temperatures, irregular rainfall, flooding, and increased in disease incidence will all affect global production and reduce farmers' productivity (Ogundari et al., 2017). Future changes in temperature, carbon dioxide levels, and precipitation due to global warming are expected to have an effect on rice production. Rapid climate change repercussions include the adverse effects of extreme weather on rice production systems and food availability (Chandio, Magsi, & Ozturk, 2020; Muoneke, Okere, & Nwaeze, 2022).

Rice, a staple food for the majority of the world's population, is consumed by approximately 3 billion people every day (Krishnan, Ivanov, Masulis, & Singh, 2011). Wetland rice farming is one of the largest contributors to atmospheric methane (CH4) and approximately 90% of the world's rice is grown in flooded fields, where the anaerobic conditions are ideal for the formation of methane (Bouwman, 1991; Matthews, Fung, & Lerner, 1991). Bouwman (1991) estimated that rice production could increase by 65% between 1990 and 2025, leading to an increase in annual methane emissions from 92 Tg CH4 to 131 Tg in 2025. A staple food for over half of the world's population, rice is the agricultural product with the third highest global production, after maize and sugar cane.

The variety of empirical studies examining the EKC hypothesis's reliability is evident from the current review of the empirical literature. ED must be measured with agriculture included, however, in countries that rely heavily on agriculture. Therefore, this study validates the EKC using data from the top ten rice-producing countries in the world. Asia is the largest producer and consumer of rice, with China, India, Thailand, and Indonesia among the largest producers and consumers (Irshad, Xin, & Arshad, 2018; Matthews et al., 1991).

Our research contributes in numerous ways to the existing body of literature. First, we examine the aggregated validity of the inverted U-shaped EKC and then the disaggregated reliability. Second, we test the validity of the EKC in the top 10 rice-producing countries from 1995 to 2018, which has not been examined in a study using this sample to the best of our knowledge. Thirdly, no other study has used PM 2.5 emissions, PM 10 emissions, and CH4 emissions emitted from the rice cultivation process as proxies for ED separately at aggregated (i.e., overall economy) and disaggregated (i.e., agriculture sector) levels (Bouwman, 1991; Matthews et al., 1991). Fourthly, we used two distinct models (i.e., aggregated and disaggregated) for each environmental indicator (i.e, PM 2.5, PM10, and CH5).

The rest of this article is arranged as follows: The framework of the environmental Kuznets curve is described in Section 2. The third section describes the data, while the fourth section discusses the empirical framework. Section 5 presents the findings and discussion of growth in general. The sixth section discusses the empirical results, and the last section concludes the paper with policy implications.

2. Data And Methodology

2.1 Data

This study aims to investigate the validity of the EKC at aggregate and disaggregate levels. For the aggregated levels, overall economic growth is considered and for the disaggregated levels, the growth of the agriculture sector is used for empirical analysis. A panel of the top 10 rice-producing nations in the world is considered for this purpose. Asia accounts for roughly 90% of global rice consumption and production (Wassmann et al., 2009). China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, Japan, the Philippines, and Brazil are, the top 10 rice-producing countries, are selected in this study. As a result of the most severe anthropogenic activities, such as agricultural operations and rapid urbanization, many countries around the globe are grappling with environmental pollution (Kijima, Nishide, & Ohyama, 2010).

Three dependent variables are used as proxies for ED: PM 2.5 emissions, PM 10 emissions (i.e., air pollution), and CH4 emissions from rice cultivation processes. The indicators of ED have been obtained from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR). GDP per capita (constant 2015 US$), population density (people per square kilometer of land area), agriculture, forestry, and fishing logs, value added per worker logs (constant 2015 US$), and share of urban population collected from the World Bank, World Development Indicators (WDI), are included as explanatory variables. Moreover, we used in the IMF's Financial Development Index (International Monetary Fund).

2.2 Empirical Model

The theoretical relationship between economic growth and ED has been described by (Allard et al., 2018; Grossman & Krueger, 1991; Selcuk et al., 2021) as follows:

$$ED_{it} = \alpha_{it} + \beta_1 LEG_{it} + \beta_2 LEG_{it}^2 + \beta_3 X_{it} + \epsilon_{it}$$

1

Where ED represents environmental degradation, LEG represents the log of GDP per capita at time t in country i and X represent all other variables that may impact environmental quality. The coefficient α measures the average pressure on environmental quality when income has no effect, the β's shows the direction and significance of the explanatory variables, while ε is the error term. The sign of the different β's defines the shape of the EKC.

We estimate an empirical model of the relationship between ED which consists of three different gases (i.e., environmental pollution PM2.5, PM10 and CH4 is global warming) emitted from the rice cultivation process and overall economic growth using the following explanatory variables: log of GDP per capita (constant 2015 US$) (LEG) and its square, log of population density (people per square kilometer of land) (LPD) (Xie, Xu, & Liu, 2019), share of the urban populace (urban) (Kijima et al., 2010), and financial development index (FD). The model is as follow:

$$ED_{it} = \alpha + \alpha_{i1}LEG_{it} + \alpha_{i2}LEG_{it}^{2} + \alpha_{i3}LPD_{it} + \alpha_{i4}Urban_{it} + \alpha_{i5}FD_{it} + \epsilon_{it}$$

2

At disaggregate level, we estimate the relationship between ED and the following sectorial level explanatory variables: Log of Agriculture, forestry, and fishing value added per worker (constant 2015 US$) (LAEG), its square, LPD, urban, and FD. The empirical model is follow:

$$ED_{it} = \alpha + \alpha_{i1}LAEG_{it} + \alpha_{i2}LAEG_{it}^{2} + \alpha_{i3}LPD_{it} + \alpha_{i4}Urban_{it} + \alpha_{i5}FD_{it} + \epsilon_{it} \ (3)$$

Where t = 1995, 1996……..2018 and i = 1, 2, 3….10. In this model subscript i and subscript t show the country and time, α and ε denote the intercept and error term respectively, β's are the coefficients of the explanatory variables. Eq. 2 at aggregate level and Eq. 3 estimated at disaggregate level are estimated. As the Error is unknown, to obtain the consistent estimates we used the Feasible General Least Squares (FGLS) and panel-corrected standard error (PCSE) technics to estimate the models because when T = 24 & N = 10, FGLS is a superior choice (by reason T is greater than N) as suggested by the Parks-Kmenta method.. The FGLS outperforms other competing models like the panel fixed effect (FE) and the panel random effect (RE) models, where cross-sectional differences are exclusively explained by changes in the intercept. Additionally, FGLS models can be made resilient to cross-sectional dependence, serial autocorrelation, and heteroscedasticity by altering cross-sectional-specific standard errors (Hanif, Arshed, & Aziz, 2020). For further analysis of robustness, we used the generalized method of moments (GMM) which takes care of the problem of endogeneity. When T > N case (Panel time series study), there is a high likelihood of the problem of heteroscedasticity and autocorrelation, so we use the different types of diagnostics tests like the Modified Wald test to test the issue of heteroscedasticity, the Wooldridge test to check the presence of serial correlation, and Breusch Pagan Lagrange multiplier (BPLM) test to detect the presence of cross-sectional dependence (CSD)

2.3 Econometrics Techniques

The panel Feasible Generalized Least Square (FGLS) model was employed in this investigation to estimate the models depicted in Equations 1 to 3. This model incorporates differences in cross-sections (unobserved heteroscedasticity) through changes in the estimates' standard errors (Davidson & MacKinnon, 1993). FGLS outperforms other competing models like the panel fixed effect (FE) model and the panel random effect (RE), where cross-sectional differences are exclusively explained by changes in the intercept (Hassan, Bukhari, & Arshed, 2020; Shi, Visas, Ul-Haq, Abbas, & Khanum, 2022). Additionally, FGLS models can be made resilient to cross-sectional dependence, serial autocorrelation, and heteroscedasticity by changing cross-sectional-specific standard errors (Davidson & MacKinnon, 1993; Maddala & Lahiri, 2006). The following gives a mathematical representation of the FGLS robust model.

$$\mathrm{B}_{GLS} = \left(\acute{Z}\ \Omega^{-1} Z\right)^{-1} \acute{Z}\ \Omega^{-1} y$$

5

$$Var\left(\mathrm{B}_{GLS}\right) = \left(\acute{Z}\ \Omega^{-1} Z\right)^{-1}$$

6

$$\Omega = \sum\nolimits_{n*n} \Theta I_{T_i * T_i}$$

7

$$\sum\widehat{i,j} = \frac{\hat{\epsilon}_i \widehat{\epsilon_j}}{T}$$

8

Here, while computing the coefficients and standard errors, the identity matrix $\boldsymbol{\Omega}$ is modified to take into account heteroscedasticity and autocorrelation. According to Beck and Katz (1995), the GLS model is more effective than alternatives like the PCSE or the robust FE model (Al-Malki, Hassan, & Ul-Haq, 2022; Hanif et al., 2020; Shi et al., 2022).

3. Results And Discussion

In this section, we discuss the results of overall economic growth as well as growth in the agricultural industry. We used the FGLS technique to test the validity of EKC, and the PCSE technique is used to test the accuracy of the results. Both of these techniques produced consistent and robust results. The empirical findings of the relationship between economic growth and PM2.5 and CH4 when employed as the dependent variable are discussed below.

Table 1 provides descriptive statistics for the dependent and explanatory variables for the sample of the top ten rice-producing countries over a 24-year period. Except for the urbanization rate and the indicator of financial development, all variables are expressed in logarithmic form. Except for urbanization, the sample's other variables have a low minimum value, maximum value, mean, and standard deviation. The average values of all variables range from 0.4 to 7.8 percent, but the average value of urban population share is 46.04 percent, which is slightly higher.

Table 1
Descriptive Statistics

Variable	N	Mean	SD	Mini	Maxi
$LPM_{2.5}$	240	1.9737	0.9986	0.1853	3.6213
LPM_{10}	240	2.4333	0.9985	0.6448	4.0808
LCH	240	7.5052	1.0141	5.1579	9.5765
LEG	240	7.8900	1.1852	5.4208	10.4965
LPD	240	5.2146	1.0072	2.9644	7.1226
LAEG	235	7.6988	0.9474	6.2090	9.9805
Urban	240	46.0489	21.1067	21.693	91.616
FD	240	0.4045	0.1945	0.0765	0.8918

3.1 Aggregate model results

The outcomes of several diagnostic tests are represented in Table 2. There is heteroscedasticity problem, as evidenced by the results of the modified Wald test when LPM2.5, LPM10, and LCH are each used as the dependent variable. At the overall level, serial correlation and cross-sectional dependence exist.

Table 2
Panel Diagnostic Tests (Aggregate levels case)

Test	Issues	LPM25	LPM10	LCH
Modified Wald ($\chi 2$)	Heteroscedasticity	729.98***	730.00***	1110.40***
Wooldridge Test	Serial correlation	42.84***	42.86***	44.69***
BP-LM Test	CSD	187.94***	187.95***	149.22***
Note: *show 0.05, **show 0.01, ***show 0.001. Wald test for the group-wise heteroscedasticity in FE (fixed effect) regression model. H0 = sigma(i)^2 = sigma^2 for all i: No heteroscedasticity problem. Serial correlation = H0: No autocorrelation.				

The findings of the investigation into the relationship between ED and economic expansion are presented in Table 3. The results of economic growth are displayed in columns 1 and 4 when the PM2.5 level is used as a proxy for ED. The empirical findings regarding the relationship between ED and LEG are displayed in columns 2 and 5 when PM10 is used as the dependent variable. In contrast, the empirical findings regarding the relationship between economic growth and LCH are displayed in columns 3 and 6. The fact that GDP per capita is positive and statistically significant in both the FGLS and PCSE models demonstrates the robustness of our findings. Table 3 below shows the positive relationship between GDP per capita and environmental pollution on the one hand, and GDP per capita and global warming on the other hand.

Table 3
Environmental degradation and Economic growth

	FGLS			**PCSE**		
	1	2	3	4	5	6
LEG	3.44***	3.44***	1.93***	2.90***	2.90***	1.79***
	(0.139)	(0.139)	(0.119)	(0.344)	(0.344)	(0.401)
LEG^2	-0.230***	-0.231***	-0.130***	-0.201***	-0.201***	-0.126***
	(0.008)	(0.008)	(0.007)	(0.019)	(0.020)	(0.023)
Constant	-10.53***	-10.07***	0.623***	-8.099***	-7.639***	1.386
	(0.580)	(0.581)	(0.469)	(1.430)	(1.431)	(1.660)
Wald Stats	8821.35	8821.37	470.44	567.40	567.40	186.48
P-Val	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Obs	240	240	240	240	240	240

Note: $PM_{2.5}$ is the dependent variable in Columns 1 & 4, PM_{10} is dependent variable in columns 2 & 5 and CH4 is the dependent variable in Columns 3 & 6. ***' ** and * are significance at the 1%, 5% and 10% levels respectively.

As shown in column 1, a 1% rise in economic growth causes a 3.4% point increase in environmental pollution. The coefficient of the square of LEG is negative and statistically significant in all specification irrespective of the estimation technique used. This demonstrates that at lower levels of economic growth, climate pollution rises but as economic growth reaches a certain threshold, environmental pollution falls, validating the inverted U-shaped EKC in these top ten rice-producing countries. The results of PM2.5 show a positive relationship with GDP and a negative relationship with its square. These findings are similar to those reported by (Xie et al., 2019) for 249 Chinese cities. The results of Ch4 with GDP also show an inverted U-shaped EKC, which is consistent with (Djoukouo, 2021) for six Central African Economic and Monetary Community countries.

3.2 Robustness checks

We checked the robustness of our estimates by including various environment-related variables in the baseline model. In Table 4, we included urban, LPD, and FD variables to test the robustness of the FGLS model. The coefficient of economic growth is positive and statistically significant, while that of its square is negative and statistically significant. This suggests that the validity of the inverted U-shaped EKC in these top ten rice-producing counties is not affected after the inclusion of other variables.

Table 4
Environmental degradation and Economic growth (Robustness Check)

	1	2	3	4	5	6
LEG	2.57***	2.83***	2.27***	1.21***	1.37***	1.32***
	(0.214)	(0.241)	(0.137)	(0.026)	(0.028)	(0.027)
LEG^2	-0.151***	-0.170***	-0.161***	-0.027***	-0.040***	-0.049***
	(0.011)	(0.014)	(0.009)	(0.001)	(0.001)	(0.001)
Urban	-0.031***	-0.026***	-0.016***	-0.066***	-0.062***	-0.059***
	(0.002)	(0.002)	(0.003)	(0.001)	(0.001)	(0.001)
LPD		0.060**	0.083***		0.061***	0.055***
		(0.024)	(0.016)		(0.002)	(0.004)
FD			1.720***			1.079***
			(0.248)			(0.031)
Cons	-7.37***	-8.81***	-6.16***	2.70***	1.76***	2.192***
	(0.893)	(1.069)	(0.520)	(0.099)	(0.120)	(0.109)
Wald Stats	1859.07	1837.97	2060.89	16204.48	14619.69	14479.03
P-Val	0.000	0.000	0.000	0.000	0.000	0.000
Obs	240	240	240	240	240	240

Note: PM2.5 is the dependent variable in Columns 1–3, while LCH is the dependent variable in columns 4–6 in all FGLS models. ***’ ** and * are significance at the 1%, 5% and 10% levels respectively.

The statistical significance of our findings was demonstrated by the p-values for all the variables, which support the validity of the inverted U-shaped EKC at the 1% level of significance. This table demonstrates that even after accounting for these variables, our findings are still statistically significant and the shape of the EKC is unaffected.

Table 5
Environmental degradation and Economic growth (GMM Estimates)

VARIABLES	LPM25	LPM10	LCH
LEG	2.417***	2.417***	1.320***
	(0.425)	(0.425)	(0.440)
LEG^2	-0.169***	-0.169***	-0.0487*
	(0.0276)	(0.0276)	(0.0286)
Urban	-0.0307***	-0.0307***	-0.0604***
	(0.00563)	(0.00563)	(0.00582)
LPD	-0.0103	-0.0103	0.0581
	(0.0533)	(0.0533)	(0.0551)
FD	2.972***	2.972***	1.139**
	(0.472)	(0.472)	(0.488)
Constant	-6.105***	-5.646***	2.207
	(1.834)	(1.834)	(1.896)
Observations	240	240	240
Note: ***’ ** and * are significance at the 1%, 5% and 10% levels respectively.			

We also employed the GMM approach, results are presented in Table 5, to deal with the problems caused by endogeneity so that the results are as robust as possible. Using this estimation approach, our results show the same trends in the signs and significance of the coefficient of the core variable.

3.3 Disaggregate model results

At the sectoral level, we also apply the modified Wald, Wooldridge, and BP-LM diagnostic tests. The results of these tests reveal the issues of heteroscedasticity, serial correlation, and cross-sectional dependence in the data. The results are presented in Table 6 below.

Table 6
Panel Diagnostic Tests for Sectoral Analysis

Test	Issues	LPM25	LPM10	LCH
Modified Wald (χ2)	Heteroscedasticity	356.65***	356.66***	1218.12***
Wooldridge Test	Serial correlation	51.72***	51.73***	61.71***
BP-LM Test	CSD	283.73***	283.742***	228.76***
Note: *show 0.05, **show 0.01, ***show 0.001. Wald test for the group-wise heteroscedasticity in FE (fixed effect) regression model. H0 = sigma (i) ^2 = sigma^2 for all i: No heteroscedasticity problem. Serial correlation = H0: No autocorrelation.				

Similar to how we addressed the findings at the level of the economy as a whole, we now describe the results at disaggregate level. Table 7 displays the results of ED and the growth of the agricultural industry. All of the estimates of the FGLS models reveal a statistically significant link between ED and LAEG, and the PCSE estimates validate these results. The first column of Table 7 reveals that environmental pollution increases by 3.5% for every 1% increase in agricultural growth. The coefficient of the square of LAEG is native and statistically significant, demonstrating the sector-level validity of the EKC. These results are similar to those of (Sarkodie & Strezov, 2019) and Uddin (2020) for 54 and 115 countries, respectively.

In Table 7, when CH is used as a proxy for ED, the estimates in columns 3 and 6 show LAEG and ED have a positive and significant relationship. The square of AEG has a negative and statistically significant coefficient, suggesting that an inverted U-shaped EKC is found at the disaggregate level. These findings are in line with those of (Ogundari et al., 2017), for Sub-Saharan African countries and (Uddin, 2020), for 115 countries.

Table 7
Environmental degradation and Sectoral growth

	FGLS			PCSE		
	1	2	3	4	5	6
LAEG	3.56***	3.57***	2.14***	3.62***	3.63***	1.79*
	(0.195)	(0.196)	(0.260)	(0.577)	(0.578)	(0.759)
LAEG-2	-0.251***	-0.251***	-0.150***	-0.259***	-0.259***	-0.110**
	(0.011)	(0.012)	(0.016)	(0.034)	(0.034)	(0.023)
Constant	-10.40***	-9.949***	0.097	-10.304***	-9.844***	3.875
	(0.782)	(0.782)	(1.028)	(2.362)	(2.362)	(3.101)
Wald Stats	2284.71	2284.69	222.19	643.75	643.76	157.10
P-Val	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Obs	235	235	235	235	235	235

Note: PM2.5 is the dependent variable in Column 1 & 4, while PM10 is dependent variable in column 2 & 5. LCH is the dependent variable in Column 3 & 6

3.4 Robustness checks

To test the robustness of the core findings, we incorporate a number of environmental variables at the sector level. The results with these additional factors, which include Urban, LPD, and FD, are presented in Table 8. In all of the FGLS models, with the exception of the squares of LAEG and Urban, the coefficients of the other variables are positive and statistically significant. The significance level is also indicated by the p-values of the Wald statistics, which indicate that our results are robust and that the inverted U-shaped EKC holds at the sector level. Table 9 displays the GMM approach results for further robustness checks.

Table 8
Environmental degradation and Sectoral growth (Robustness Check)

	1	2	3	4	5	6
LAEG	3.58***	5.02***	3.76***	1.89***	3.29***	2.73***
	(0.285)	(0.378)	(0.242)	(0.373)	(0.382)	(0.296)
$LAEG^2$	-0.217***	-0.313***	-0.255***	-0.064***	-0.159***	-0.127***
	(0.016)	(0.022)	(0.014)	(0.022)	(0.023)	(0.018)
Urban	-0.032***	-0.023***	-0.018***	-0.065***	-0.054***	-0.052***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)
LPD		0.154**	0.130***		0.202***	0.179***
		(0.027)	(0.013)		(0.029)	(0.021)
FD			1.375***			1.616***
			(0.222)			(0.16)
Cons	-11.096***	-17.74***	-12.16***	-0.154	-6.91***	-2.895**
	(1.171)	(1.642)	(0.982)	(1.524)	(1.646)	(0.1.26)
Wald Stats	2186.64	2439.77	3049.82	811.73	1104.43	1963.87
P-Val	0.000	0.000	0.000	0.000	0.000	0.000
Obs	235	235	235	235	235	235
Note: PM2.5 is the dependent variable in Columns 1–3, while LCH is the dependent variable in columns 4–6 in all FGLS models.						

Table 9
Environmental degradation and Sectoral growth (GMM Estimates)

VARIABLES	LPM25	LPM10	LCH
LAEG	4.734***	4.734***	4.019***
	(0.760)	(0.760)	(0.805)
$LAEG^2$	-0.314***	-0.314***	-0.214***
	(0.046)	(0.046)	(0.049)
Urban	-0.0296***	-0.0296***	-0.0600***
	(0.006)	(0.006)	(0.007)
LPD	0.0789	0.0789	0.135**
	(0.0600)	(0.0600)	(0.0636)
FD	2.471***	2.471***	1.724***
	(0.397)	(0.397)	(0.421)
Constant	-15.62***	-15.16***	-9.159***
	(3.254)	(3.254)	(3.449)
Observations	235	235	235
Note: ***’ ** and * are significance at the 1%, 5% and 10% levels respectively.			

4. Conclusion And Policy Implication

In this study, the relationship between ED and economic growth as was the validity of the EKC at both aggregate and disaggregate levels in the top ten rice-producing countries around the world was investigated. We used three different gases, methane, CH4 greenhouse gases, PM2.5 and PM10 air pollution, emitted during the rice growing process as proxies for environmental deterioration. The years 1995 through 2018 were examined through the lens of a panel comprised of the top ten rice-producing countries. According to the above analysis, there is a significant relationship between ED and economic growth. All ED measures exhibit a positive relationship with economic growth; however, this relationship reverses when the square of GDP is considered. These findings support the validity of the inverted U-shaped EKC at both aggregate and disaggregated levels.

The findings of this study reveal that with the inclusion of additional environmental-related factors, our core results are robust, and the shape of the EKC does not change at both aggregate and disaggregate models. As a result, we conclude that the validity of the inverted U-shaped EKC in the top 10 rice-producing countries suggests that strict environmental legislation, efficient energy use, and green technologies can reduce emissions as the economy and agriculture sector grow.

Natural resource conservation policies to address the issue of resource extraction, as well as policies to increase farmers' environmental awareness and knowledge of how to control agro-environmental contamination, would be beneficial. Reducing global emissions appears to be quite difficult. To develop methods for reducing CH_4 emissions from wetland rice fields, research into the relationships between soil chemical and physical properties, soil, water, and crop management, and methanogens is required. These procedures should not negatively affect rice production. Varietal adaptation may provide relatively simple opportunities for farmers to reduce emissions, provided that rice yields are not reduced. The government can impose a green tax on polluting businesses and compensate farmers who purchase tractors with clean technology.

Declarations

Statements & Declarations

Ethics Approval: Not Applicable

Consent to Publication: All authors have consented to publish

Consent to Participate: Not Applicable

Authors' Contributions: The conceptualization was done by JH & HV. Data was collected by JH & HV, and was arranged and transformed into Stata formed by JH & AHC. AHC, JH, HV & BS finalized the methodology for analysis and analysis. HV & NA wrote the original draft and JH & BS improved the draft. AHC, BS & HV reviewed and edited. JH & BS supervised the whole study. All authors read and approved the final manuscript.

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