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Implementation of Neutrosophic Logic for Food Security and Agricultural Productivity Analysis in South Asian Countries

Muhammad Yaseen [1], Korntima Phattanasin [2*], Jamil Afzal[3] and Muhammad Adeel Afzal [4]

[1] School of International Law, Southwest University of Political Science and Law, Chongqing, China; yaseenadv191686@gmail.com

[2] School of Law, Walailak University, Thailand; kphattanasin@gmail.com

[3] International Islamic University Malaysia; sirjamilafzal@gamil.com

[4] College of Economics & Management Science, China Three Gorges University, China; adeel@ctgu.edu.cn

* Correspondence: kphattanasin@gmail.com

Abstract: Agricultural productivity in South Asia heavily depends on carbon emission factors (CO_2, CH_4, N_2O), together with climatic variability and food security, which profoundly affect economic stability along with regional food security. This combined classical and neutrosophic analytic methodology evaluates the interrelationships through the analysis of data from Afghanistan, Bangladesh, India, Pakistan, and Sri Lanka (2002–2020). The study demonstrates that food security (logfs) generates the highest positive relationship with crop productivity at a coefficient = 0.871 ($p < 0.01$), yet farmer livelihoods (logfl) produce a negative result, documenting resource accessibility differences. The positive connection between Corbin emissions and productivity levels stands out statistically as significant ($p < 0.01$) with a coefficient value of 0.026. The neutrosophic analysis demonstrates superiority over classical methods because it effectively includes both data variability and indeterminacy by showing that India's crop productivity remains within the span of 60.9–115.7 and is not limited to the single-point estimate of 88.3. The findings underscore the need for climate-smart agriculture, emission reduction strategies, and enhanced farmer support systems. The proposed policies stress regional teamwork and superior analytical methods alongside sustainable methods to build climate resilience and secure continuous South Asian food safety in the long run.

Keywords: Agricultural Productivity; Food Security; Corbin Emissions; Neutrosophic Analysis

1. Introduction

Agricultural productivity stands as a critical determinant of economic stability and food security in South Asian countries, which harbor some of the world's largest populations engaged in farming activities[1]. Three main challenges affect the region because of its mix of Carbon emission factors and food security conditions and variable climatic conditions[2]. The identification of these interactions becomes essential to build sustainability strategies which improve productivity levels under the critical situations caused by climate change and environmental destruction. In South Asia agricultural practices generate greenhouse gas emissions from various farming activities which are expressed through Corbin emission factors composed mainly of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)[3, 4]. A study from Pathak et al.[5] shows that rice cultivation and livestock management result in high levels of regional emissions throughout the agricultural sector.

The released emissions in the environment negatively affect both environmental quality and soil health and crop productivity while forming a feedback loop that worsens food insecurity[6].
The combination of emission factors with unstable climatic variables endangers agricultural outputs in South Asia[7, 8]. IPCC (2014) has warned that the climate-sensitive region faces profound sensitivity to climate change which threatens a decrease in crop yields particularly for wheat and rice supplies[9]. The findings presented by Lobell et al.[10] show how crop productivity reacts to climate changes because irregular precipitation combined with higher temperatures cause severe yield losses that both reduce food availability and impact farmer income stability. Ubiquitous dependence of food security builds on agricultural productivity in South Asia due to the region's millions of people who practice agriculture for income[11]. The Food and Agriculture Organization (FAO, 2018) explains that attaining food security requires enhancing both food production and providing all communities with sufficient nutritionally sound food resource[12]. Food security improves when farmers produce more food but stabilization of their systems becomes essential to survive economic and environmental pressures[13]. The researchers conducted their analysis through Fuzzy Set Qualitative Comparative Analysis (FSQCA) allowing them to understand which multiple combinations of factors create agricultural productivity[13]. FSQCA analyzes multiple causal factors through their combinations instead of independent variables because it recognizes that food-related systems perform optimally from coordinated interactions between pollutant variables and atmospheric conditions and nutritional resources. Researchers need to discover which exact combinations of factors create productive outcomes so they can create strategic solutions for agricultural systems[14].
Research findings about sustainable agriculture, together with food security evidence from South Asian countries will expand academic knowledge regarding this field. The aims of the current study are

- To provide a set of implementable policy recommendations to help South Asian policymakers tackle emissions alongside climate variability issues toward improved regional food security.
- To understand how South Asian countries' food security is affected by the Carbon emission factors and climatic conditions using Neutrosophic logic.

2. Literature Review and Theoretical Justification

The research on food security has identified more than 200 distinct meanings according to Hoddinott[15, 16]. The "World Food Conference of FAO1" first endorsed this definition in 1974, following their declaration that "food availability is considered as the sole component of measuring food security." The Food and Agriculture Organisation issued its final version of food security definition in 2002 as "the state in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2002). The definition of food security includes all four key components according to the guidelines outlined by Kumar and Sharma[17] in their work. Assessing climate change requires knowledge as a fundamental first step to evaluate its effect on food security[18]. Climate change represents the evolving weather patterns along with deadly weather phenomena, including elevating global heat and precipitation and ocean levels according to Church and White[19]. The quantitative assessment of climate change effects on food security requires three climatic parameters which include CO_2 emissions together with average annual rainfall measurements and average annual temperature evaluation. Some experts link the regular occurrence of extreme events blocking food accessibility to environmental modifications that cause growing CO_2 emissions along with increasing temperatures and changed annual precipitation patterns[20, 21]. A decline in agricultural output caused by climate change results in reduced soil fertility, thus directly affecting food security, according to FAO (2008a). Studies validate that food security enhancement occurs through effective influence of food availability dimension using productive agricultural approaches that maintain climate resilience[22]. Nationwide food security levels increase when farmers extend their cereal cultivation areas and boost their fertilizer consumption rates.

2. 1 Corbin Emission Factors and Agricultural Productivity

Corbin emission factors refer to the various greenhouse gases emitted through agricultural practices, primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [23, 24]. Agricultural activities contribute significantly to global emissions, making it imperative to assess their impact on agricultural productivity. Studies have demonstrated that high levels of emissions correlate with negative outcomes in agricultural yield and soil health[25]. For instance, a study by Rose et al. indicates that regions with intensive agricultural practices that emit higher greenhouse gases tend to experience reduced soil fertility and increased pest pressures, both of which detrimentally affect crop yields[26].

2.2 Climatic Factors Influencing Agriculture

Climatic factors, such as temperature variability, precipitation patterns, and the frequency of extreme weather events, play critical roles in determining agricultural productivity. Research indicates that shifts in climatic patterns due to climate change are altering planting seasons, crop growth periods, and overall agricultural outputs[27]. Lobell et al. highlight that rising temperatures are associated with decreased maize yields in sub-Saharan Africa, underscoring the vulnerability of specific crops to climatic changes[28]. Additionally, a meta-analysis by Chaudhary et al. (2016) illustrates that increased precipitation variability exacerbates risks, with implications for food security as consistent crop production becomes more elusive[29].

2.3 Food Security and Agricultural Productivity

Food security is intrinsically linked to agricultural productivity, with FAO (2019) asserting that sustainable agricultural practices are foundational to achieving global food security goals. Poor agricultural productivity due to adverse climatic effects and high emissions can threaten food availability, accessibility, and utilization. According to Godfray et al., enhancing agricultural productivity through sustainable practices is critical for meeting the nutritional needs of a growing global population[30]. Furthermore, food security encompasses not only availability but also socio-economic factors, suggesting that improving agricultural productivity in resource-constrained areas must consider local socio-economic conditions[30].

2.4 Interplay between Agricultural Productivity and Farmer Livelihoods

The link between agricultural productivity and farmer livelihoods is multifaceted. Higher agricultural productivity can lead to increased farm incomes, which can be reinvested into agricultural improvements or diversified into other income-generating activities[31, 32]. However, the benefits of increased productivity are not always equitably distributed among farmers; access to resources, technology, and markets can significantly influence the extent to which productivity gains translate into improved livelihoods[33]. Furthermore, socio-economic factors such as land tenure security, access to credit, and education play critical roles in determining how agricultural productivity impacts farmer livelihoods[34].

2.5 Impacts on Social Capital and Community Cohesion

Agricultural productivity also influences social capital and community cohesion within rural areas; increased agricultural productivity can enhance social stability[35]. Agriculture serves as the backbone of rural economies in South Asia, providing livelihoods for a significant portion of the population. The practice of agriculture not only fosters economic ties but also facilitates social interactions and community building. Scholars like Pretty emphasize that agricultural activities often involve communal practices, such as collective farming and shared labor, which help build social capital[36]. Climate change disrupts agricultural productivity through extreme weather events and changing growing conditions, communities face challenges that might erode social ties. A decline in yields can lead to increased competition for dwindling resources, creating tensions within communities. Table 1 show the variables and their measurement information.

Table 1: Variable measurement

Variable	Notation	Measurement	Data source
Crops Productivity (Dependent)	CP	Crops production index	WDI
Corbin Emission (Independent)	CE	CO2 emission (kt) index	WDI
Climate Factor	CF	Temperature change	FAO
Technological advancement	TA	Fertilizer consumption (% of fertilizer production) index	WDI
Food Security	FS	Food production index	WDI
Farmer Livelihood	FL	Agricultural land (sq. km) index	WDI
Rural Community well-being	RCW	rural population growth (annual %) index	WDI

3. Methodology

The study utilizes annual data covering the period from 2002 to 2020; the focus lies on the dependent variable, which is the agricultural output; CP (Agricultural crops productivity), CF (Climate Factor), CE (Corbin Emission), TA (Technological advancement), FS (Food Security), FL (Farmer Livelihood), and RCW (Rural Community well-being) are among the independent variables.

For analysis the panel of South Asian countries that consists of Pakistan, Bangladesh, India, Sri Lanka and Afghanistan was selected. Food security, the WDI's data on the food production index is used. The data on Corbin emission, WDI's data on the CO2 emission (kt) index was used. For climate factor, we have taken the FAO's data on temperature change, for technological advancement, WDI's data on Fertilizer consumption (% of fertilizer production) index was used, the data for farmer livelihood WDI's data on Agricultural land (sq. km) index was used, for rural community well-being, WDI's data on rural population growth (annual %) index was used, and the data for agricultural crops production had also been collected from the WDI's data on crops production index.

This paper used Neutrophic techniques for interval-based analysis of different countries[37, 38]. Every variable interval must be translated into fixed point values while keeping in mind that the fix point values are determined using the average formula in the classical approach[39]. Let $C_{Ni} \in [C_{Li}, C_{Ui}]$ is an interval then the formula for classical approach can be written as:

$$C_{Ni} = \left(\frac{C_{Li} + C_{ui}}{2} \right), \ i=1,2,3,4,\ldots\ldots..Ni \qquad (1)$$

Computational algorithm for both classical analysis and neutrosophic analysis approach:

Classical Analysis approach

Step 1: Beginning of outer loop i=1 to I <= n_N

Step 2: Formula for execution:

$$C_{Ni} = \left(\frac{C_{Li} + C_{ui}}{2} \right)$$

Step 3: Calculation of each interval and graphical representation.

Step 4 Nested loop j = 0 to j<=n_N

Step 5: Increment ++ operator and move to the next index

Step 6: inside loop end

Step 7: Outer loop end

Neutrosophic Analysis approach

Step 1: Beginning of outer loop i=1 to i<=n_N

Step 2: Formula for execution:

$$i_U = \left(\frac{C(\%CP)_U - C(\%CP)_L}{C(\%CP)_U} \right)$$

Step 3: Nested loop j_L=0 to j_L<=i_U

Step 4: Calculate: $C(\%CP)_N = C(\%CP)_L + C(\%CP)_U i_N; i_N \in [i_L, i_U]$

Step 5: inside loop completion

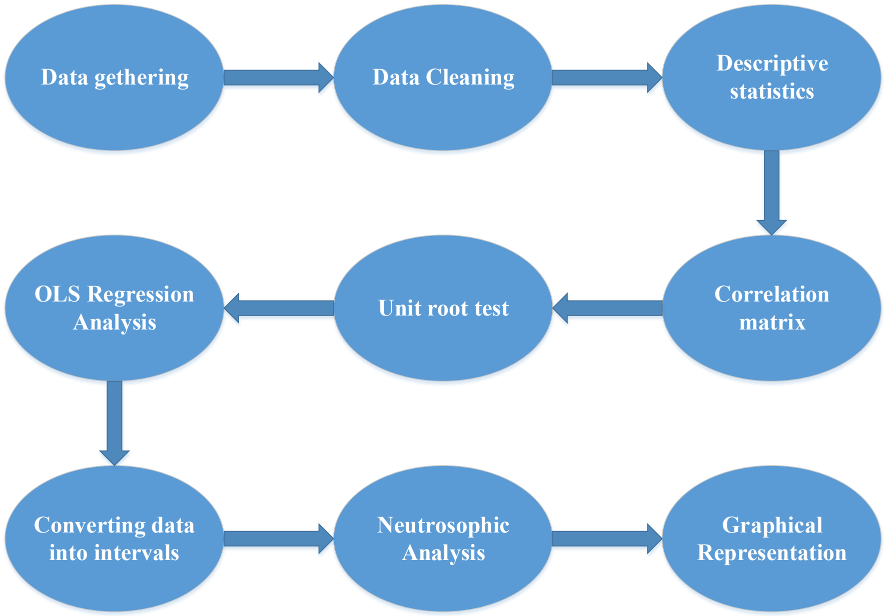
Step 6: Increment ++ operator and move to the next index

Step 7: Outer loop end

4. Data Analysis

Figure 1 indicates the methodology flow of the whole paper

Figure 1: Flowchart of methodology



4.1 Classical Analysis

The data summary reveals logcp and logfs possess comparable means (1.94) while their standard deviations remain low at 0.072 and 0.079, indicating consistent performance as shown in table 3. Observational data about emission levels and local conditions provide high variability for Logce and Logfl as measured by their standard deviations being 0.88 and 0.62. The variables logcf and logrw present negative mean scores of -0.097 and -0.1 which provide evidence about the predominantly unfavorable trends for climate and rural well-being.

Table 3: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Logcp	95	1.947	.072	1.78	2.09
Logce	95	4.799	.88	3.11	6.39
Logfs	95	1.942	.079	1.78	2.08
Logcf	95	-.097	.193	-.57	.28
Logfl	95	5.357	.624	4.36	6.26
Logta	95	2.497	.49	1.97	3.63
Logrw	95	-.1	.524	-1.7	.87

The statistical analysis shows a close relationship between crop productivity (logcp) and food security (logfs) because it exhibits a strong correlation value of 0.912 as shown in table 4. The relationship between farmer livelihood levels and carbon emissions stands at a moderate yet positive 0.624, but logta (technological advancement) shows a negative -0.399 correlation against logfl (farmer livelihood). The correlation between logrw (rural well-being) and other variables is weakly negative, yet logrw presents a small positive relationship with logcf (climate factor) (0.174).

Table 4: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) logcp	1.000						
(2) logce	0.224	1.000					

(3) logfs	0.912	0.078	1.000				
(4) logcf	0.074	-0.216	0.171	1.000			
(5) logfl	0.032	0.624	0.010	-0.066	1.000		
(6) logta	0.157	-0.399	0.186	0.120	-0.780	1.000	
(7) logrw	-0.308	-0.268	-0.282	0.174	0.320	-0.214	1.000

The Levin-Lin-Chu unit-root testing reveals that the variables LOGCP, LOGCE, LOGFS, and LOGCF maintain level stationarity I (0) with significant statistical values below 0.05 thus suitable for regression application. The results demonstrate LOGFL and LOGRW exhibit nonstationary at the level ($p > 0.05$) until being transformed through first differencing into I (1). At the first difference all variables are stationary as shown in table 5.

Table 5: Unit-root test:

Variable	I (0)		I (1)	
	T-value	P-value	T-value	P-value
LOGCP	-2.99	0.014**	-6.14	0.000***
LOGCE	-3.39	0.005***	-5.24	0.000***
LOGFS	-2.80	0.006**	-6.67	0.000***
LOGCF	-2.71	0.003***	-4.63	0.000***
LOGFL	0.17	0.567	-5.28	0.000***
LOGTA	-1.48	0.069*	-3.73	0.000***
LOGRW	1.54	0.938	-3.63	0.000***

The regression analysis shown in table 6 demonstrates that food security levels (logfs) generate the highest positive effect on crop productivity (logcp) (Coefficient=0.871 and $p<0.01$), but farmer livelihood (logfl) exhibits a negative influence ($p<0.01$). The results indicate Logce has a positive effect on crop productivity (Coef. = 0.026, $p < 0.01$) even though the association is minimal, while both Logcf and Logta show no statistical significance. The independent variable food security successfully predicts 87.1% of variations in crop productivity based on the high R-squared value of 0.871.

Table 6: Regression analysis

Logcp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Logce	.026	.006	4.57	0	.015	.037	***
Logfs	.871	.041	21.00	0	.79	.952	***
Logcf	-.019	.015	-1.26	.208	-.049	.011	
Logfl	-.032	.012	-2.74	.006	-.055	-.009	***
Logta	-.011	.01	-1.10	.273	-.031	.009	
Logrw	.017	.008	2.09	.037	.001	.033	**
Constant	.332	.082	4.05	0	.171	.492	***

*Note: *** p<.01, ** p<.05, * p<.1*

Table no 7 show the interval-based data that can be converted into the classical approach using the means formula according to equation 1. Table 8 uses the classical formula of the mean to represent the classical analysis of all data. The tables show that all intervals were transformed into fi-points via classical analysis, which did not define the variance of the interval from a minimum to a maximum value. We got a single point value of each variable. This demonstrates that classical analysis is unreliable for decision-making and for determining the problem's solution.

Table 7: Interval base data

Countries	CE	CP	FS	CF	TA	FL	RCW
Afghanistan	[1089, 11962]	[52.1, 121.8]	[61.59, 112.3]	[0.31, 1.89]	[94.18, 986.80]	[377900, 383130]	[0.63, 7.42]
Bangladesh	[25635, 95945]	[61.1, 111.8]	[58.81, 115.91]	[0.27, 1.44]	123.74, 572.97]	[91230, 99280]	[-0.17, 1.23]
India	[953537, 2458176]	[60.9, 115.7]	[59.89, 120.12]	[0.40, 1.12]	[113.40, 188.97]	[1785277.59, 1805600]	[0.26, 1.46]
Pakistan	[99837, 198739]	[72.1, 105.5]	[59.21, 115.98]	[0.27, 1.63]	[119.08, 143.18]	[352420, 370030]	[0.88, 2.80]
Sri Lanka	[10848, 23168]	[70.3, 107.3]	[70.51, 108.5]	[0.56, 1.30]	[1119.42, 4221.35]	[23100, 28120]	[0.20, 1.06]

Table 8: Classical analysis of data

Countries	CE	CP	FS	CF	TA	FL	RCW
Afghanistan	6525.5	86.95	86.945	1.1	540.49	380515	4.025
Bangladesh	60790	86.45	87.36	0.855	348.355	95255	0.53
India	1705857	88.3	90.005	0.76	151.185	1795438.795	0.86
Pakistan	149288	88.8	87.595	0.95	131.13	361225	1.84
Sri Lanka	17008	88.8	89.505	0.93	2670.385	25610	0.63

4.2 Neutrosophic Analysis

We must create a neutrosophic formula to use the neutrosophic approach. Initially, we create a formula to Assessing the Role of Corbin Emission Factors, climatic factors, and Food Security on Agricultural Crops Productivity in south Asian countries. $C(\%CP)_N$ be the neutrosopic variable for crops productivity with $C(\%CP)_N \in [C(\%CP)_L, C(\%CP)_U]$. Here $C(\%CP)_L$ and $C(\%CP)_U$ are the lower and upper values of thr interval, respectively. So, the neutrosophic formula for crops with indeterminacy $i_N \in [i_L, i_U]$ can be written as:

$$C(\%CP)_N = C(\%CP)_L + C(\%CP)_U i_N; i_N \in [i_L, i_U] \quad (2)$$

The above formula $C(\%CP)_N \in [C(\%CP)_L, C(\%CP)_U]$ is an extension of classical approach. The equation 2 was divided into two parts, $C(\%CP)_L$ and $C(\%CP)_u i_u$, determined and indeterminate, correspondingly, and $i_N \in [i_L, i_U]$, indeterminacy interval. To use ntrosophic approach $i_L=0$, we can obtain i_U by using

$$i_U = \left(\frac{C(\%CP)_U - C(\%CP)_L}{C(\%CP)_U} \right)$$

Tables 9 to 16 represent the results of a neutrosophic examination of data. These tables demonstrate that the neutrosophic analysis, which employs indeterminacy and provides complete information on the variation of data at a certain relative value, is more dependable. For example, in classical analysis, the crop's production value in India is 88.3 whereas in neturosophic analysis it gives us a complete equation 60.9 + 115.7 I_{CP} with the indeterminacy interval $I_{CP} \in [0, 0.473]$. According to the neutrosophic, crop production values are between 60.9 and 115.7 by put indeterminacy value.

Table 9: Neutrosophic analysis of CO_2 Emissions

Countries	CE	Neutro Analysis
Afghanistan	[1089, 11962]	$1089 + 11962\ I_{CE};\ I_{CE}\epsilon[0, 0.908]$
Bangladesh	[25635, 95945]	$25635 + 95945\ I_{CE};\ I_{CE}\epsilon[0, 0.732]$
India	[953537, 2458176]	$953537 + 2458176\ I_{CE};\ I_{CE}\epsilon[0, 0.612]$
Pakistan	[99837, 198739]	$99837 + 198739\ I_{CE};\ I_{CE}\epsilon[0, 0.497]$
Sri Lanka	[10848, 23168]	$10848 + 23168\ I_{CE};\ I_{CE}\epsilon[0, 0.531]$

Table 10: Neutrosophic analysis of Crops Production

Countries	CP	Neutro Analysis
Afghanistan	[52.1, 121.8]	$52.1 + 121.8\ I_{CP};\ I_{CP}\epsilon[0, 0.572]$
Bangladesh	[61.1, 111.8]	$61.1 + 111.8\ I_{CP};\ I_{CP}\epsilon[0, 0.453]$
India	[60.9, 115.7]	$60.9 + 115.7\ I_{CP};\ I_{CP}\epsilon[0, 0.473]$
Pakistan	[72.1, 105.5]	$72.1 + 105.5\ I_{CP};\ I_{CP}\epsilon[0, 0.316]$
Sri Lanka	[70.3, 107.3]	$70.3 + 107.3\ I_{CP};\ I_{CP}\epsilon[0, 0.344]$

Table 11: Neutrosophic analysis of Food Security

Countries	FS	Neutro Analysis
Afghanistan	[61.59, 112.3]	$61.59 + 112.3\ I_{FS};\ I_{FS}\epsilon[0, 0.451]$
Bangladesh	[58.81, 115.91]	$58.81 + 115.91\ I_{FS};\ I_{FS}\epsilon[0, 0.492]$
India	[59.89, 120.12]	$59.89 + 120.12\ I_{FS};\ I_{FS}\epsilon[0, 0.501]$
Pakistan	[59.21, 115.98]	$59.21 + 115.98\ I_{FS};\ I_{FS}\epsilon[0, 0.489]$
Sri Lanka	[70.51, 108.5]	$70.5 + 108.5\ I_{FS};\ I_{FS}\epsilon[0, 0.350]$

Table 12: Neutrosophic analysis of Climate Factor

Countries	CF	Neutro Analysis
Afghanistan	[0.31, 1.89]	$0.31 + 1.89\ I_{CF};\ I_{CF}\epsilon[0, 0.835]$
Bangladesh	[0.27, 1.44]	$0.27 + 1.44\ I_{CF};\ I_{CF}\epsilon[0, 0.812]$
India	[0.40, 1.12]	$0.40 + 1.12\ I_{CF};\ I_{CF}\epsilon[0, 0.642]$
Pakistan	[0.27, 1.63]	$0.27 + 1.63\ I_{CF};\ I_{CF}\epsilon[0, 0.834]$
Sri Lanka	[0.56, 1.30]	$0.56 + 1.30\ I_{CF};\ I_{CF}\epsilon[0, 0.569]$

Table 13: Neutrosophic analysis of Farmer Livelihood

Countries	FL	Neutro Analysis
Afghanistan	[377900, 383130]	$377900+ 383130\ I_{FL};\ I_{FL}\epsilon[0, 0.013]$
Bangladesh	[91230, 99280]	$91230+ 99280\ I_{FL};\ I_{FL}\epsilon[0, 0.081]$
India	[1785277.59, 1805600]	$1785277.59+ 1806500\ I_{FL};\ I_{FL}\epsilon[0, 0.011]$
Pakistan	[352420, 370030]	$352420+ 370030\ I_{FL};\ I_{FL}\epsilon[0, 0.047]$
Sri Lanka	[23100, 28120]	$23100+ 28120\ I_{FL};\ I_{FL}\epsilon[0, 0.178]$

Table 14: Neutrosophic analysis of Technological Advancement

Countries	TA	Neutro Analysis
Afghanistan	[94.18, 986.80]	$94.18+ 986.80\ I_{TA};\ I_{TA}\epsilon[0, 0.904]$
Bangladesh	123.74, 572.97]	$123.74+ 572.97\ I_{TA};\ I_{TA}\epsilon[0, 0.784]$
India	[113.40, 188.97]	$113.40+ 188.97\ I_{TA};\ I_{TA}\epsilon[0, 0.399]$
Pakistan	[119.08, 143.18]	$119.08+ 143.18\ I_{TA};\ I_{TA}\epsilon[0, 0.168]$

Sri Lanka	[1119.42, 4221.35]	1119.42+ 4221.35 I_{TA}; $I_{TA} \in [0, 0.734]$

Table 15: Neutrosophic analysis of Rural Community Well-being

Countries	**RCW**	**Neutro Analysis**
Afghanistan	[0.63, 7.42]	0.63+ 7.42 I_{RCW}; $I_{RCW} \in [0, 0.915]$
Bangladesh	[-0.17, 1.23]	-0.17+ 1.23 I_{RCW}; $I_{RCW} \in [0, 1.138]$
India	[0.26, 1.46]	0.26+ 1.46 I_{RCW}; $I_{RCW} \in [0, 0.821]$
Pakistan	[0.88, 2.80]	0.88+ 2.80 I_{RCW}; $I_{RCW} \in [0, 0.685]$
Sri Lanka	[0.20, 1.06]	0.20+ 1.06 I_{RCW}; $I_{RCW} \in [0, 0.811]$

Table 16: Result of neutrosophic analysis for interval

Countries	**CE**	**CP**	**FS**	**CF**	**TA**	**FL**	**RCW**
Afghanistan	1089 + 11962 I_{CE}; $I_{CE} \in [0, 0.908]$	52.1 + 121.8 I_{CP}; $I_{CP} \in [0, 0.572]$	61.59 + 112.3 I_{FS}; $I_{FS} \in [0, 0.451]$	0.31 + 1.89 I_{CF}; $I_{CF} \in [0, 0.835]$	94.18+ 986.80 I_{TA}; $I_{TA} \in [0, 0.904]$	377900+ 383130 I_{FL}; $I_{FL} \in [0, 0.013]$	0.63+ 7.42 I_{RCW}; $I_{RCW} \in [0, 0.915]$
Bangladesh	25635 + 95945 I_{CE}; $I_{CE} \in [0, 0.732]$	61.1 + 111.8 I_{CP}; $I_{CP} \in [0, 0.453]$	58.81 + 115.91 I_{FS}; $I_{FS} \in [0, 0.492]$	0.27 + 1.44 I_{CF}; $I_{CF} \in [0, 0.812]$	123.74+ 572.97 I_{TA}; $I_{TA} \in [0, 0.784]$	91230+ 99280 I_{FL}; $I_{FL} \in [0, 0.081]$	-0.17+ 1.23 I_{RCW}; $I_{RCW} \in [0, 1.138]$
India	953537 + 2458176 I_{CE}; $I_{CE} \in [0, 0.612]$	60.9 + 115.7 I_{CP}; $I_{CP} \in [0, 0.473]$	59.89 + 120.12 I_{FS}; $I_{FS} \in [0, 0.501]$	0.40 + 1.12 I_{CF}; $I_{CF} \in [0, 0.642]$	113.40+ 188.97 I_{TA}; $I_{TA} \in [0, 0.399]$	1785277.59+ 1806500 I_{FL}; $I_{FL} \in [0, 0.011]$	0.26+ 1.46 I_{RCW}; $I_{RCW} \in [0, 0.821]$
Pakistan	99837 + 198739 I_{CE}; $I_{CE} \in [0, 0.497]$	72.1 + 105.5 I_{CP}; $I_{CP} \in [0, 0.316]$	59.21 + 115.98 I_{FS}; $I_{FS} \in [0, 0.489]$	0.27 + 1.63 I_{CF}; $I_{CF} \in [0, 0.834]$	119.08+ 143.18 I_{TA}; $I_{TA} \in [0, 0.168]$	352420+ 370030 I_{FL}; $I_{FL} \in [0, 0.047]$	0.88+ 2.80 I_{RCW}; $I_{RCW} \in [0, 0.685]$
Sri Lanka	10848 + 23168 I_{CE}; $I_{CE} \in [0, 0.531]$	70.3 + 107.3 I_{CP}; $I_{CP} \in [0, 0.344]$	70.5 + 108.5 I_{FS}; $I_{FS} \in [0, 0.350]$	0.56 + 1.30 I_{CF}; $I_{CF} \in [0, 0.569]$	1119.42+ 4221.35 I_{TA}; $I_{TA} \in [0, 0.734]$	23100+ 28120 I_{FL}; $I_{FL} \in [0, 0.178]$	0.20+ 1.06 I_{RCW}; $I_{RCW} \in [0, 0.811]$

4.3 Graphical representation of Analysis

The graphical depiction of the classical and neurosophic analysis, based on Tables 2 and 8, are shown below:

Figure 2: Graphical Representation of CO_2 Emission

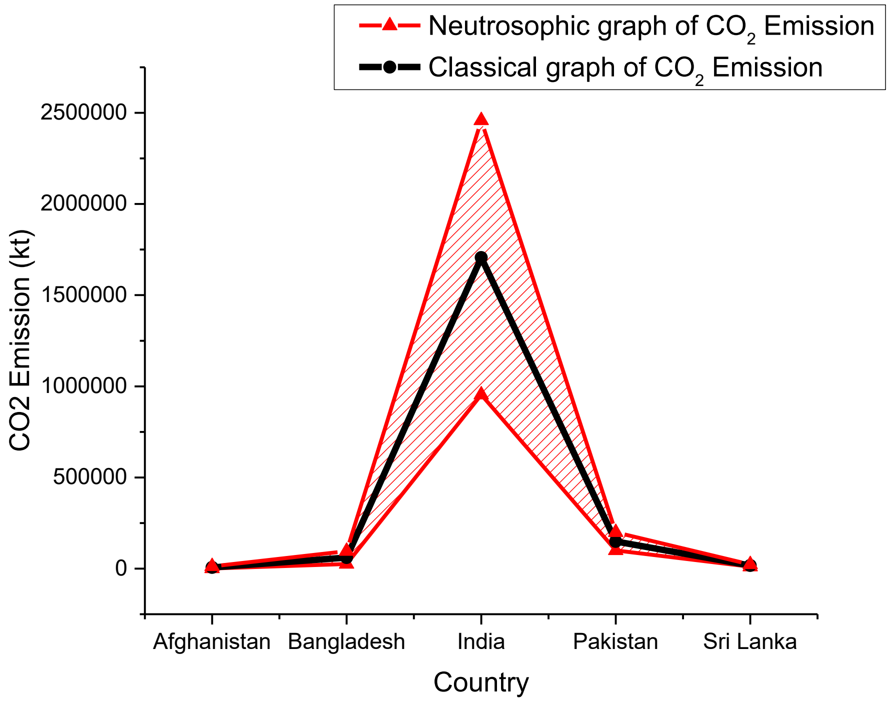


Figure 3: Graphical Representation of Crop production

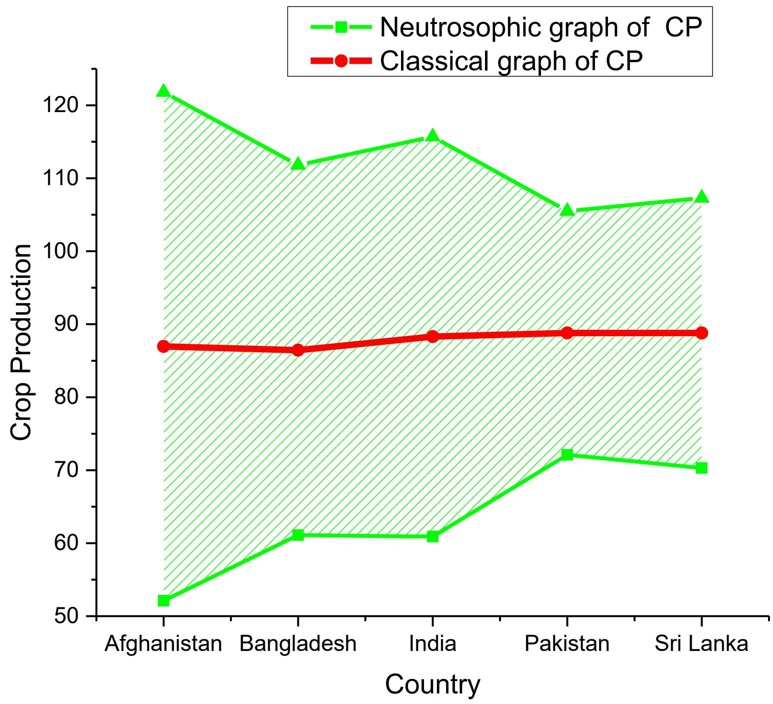


Figure 4: Graphical Representation of Food Security

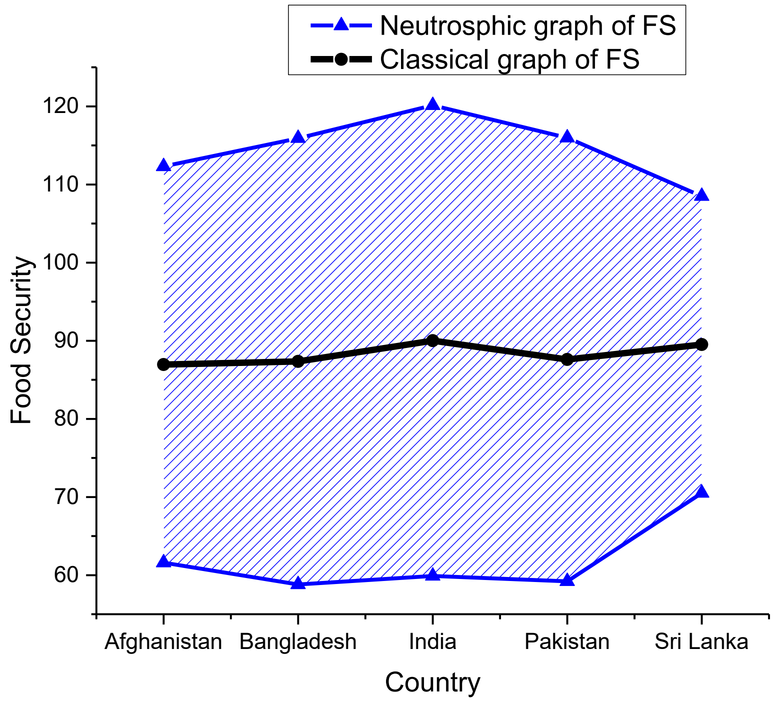


Figure 5: Graphical Representation of Climate Factor

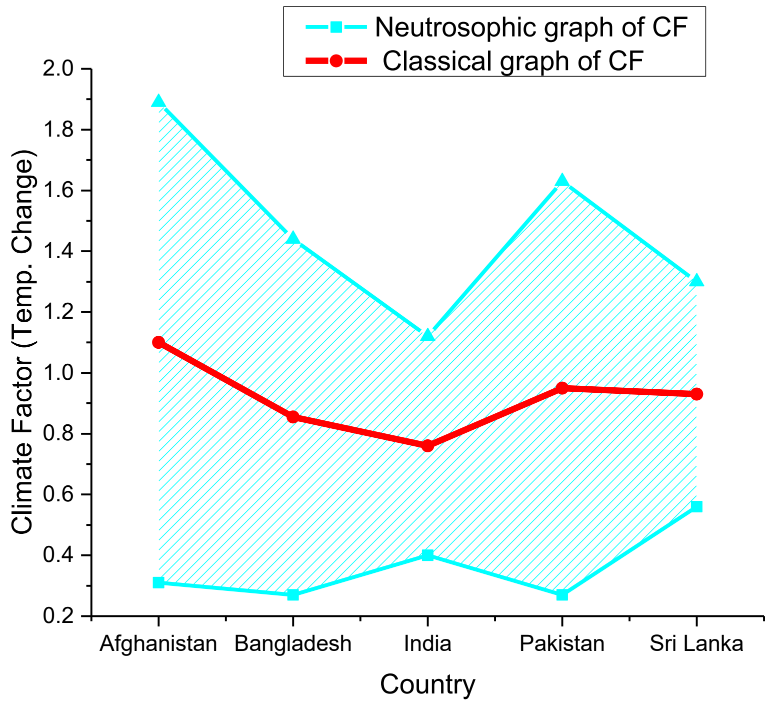


Figure 6: Graphical Representation of Farmer Livelihood

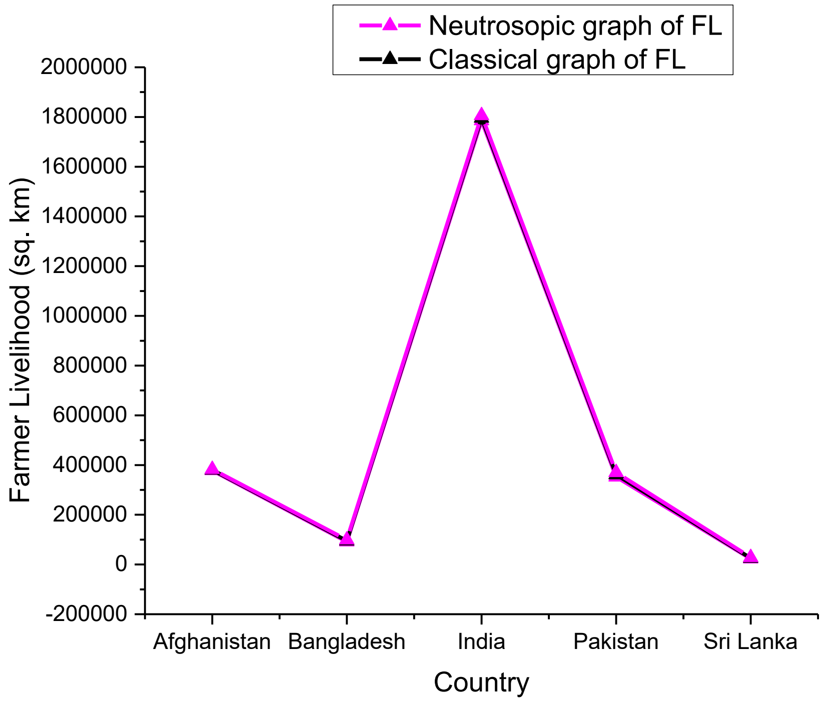


Figure 7: Graphical Representation of Rural Community Well-being

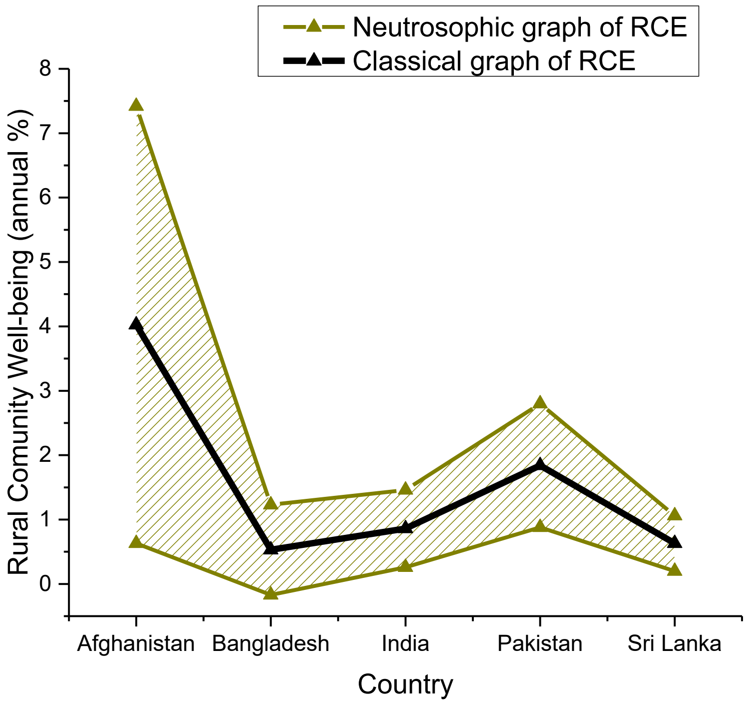
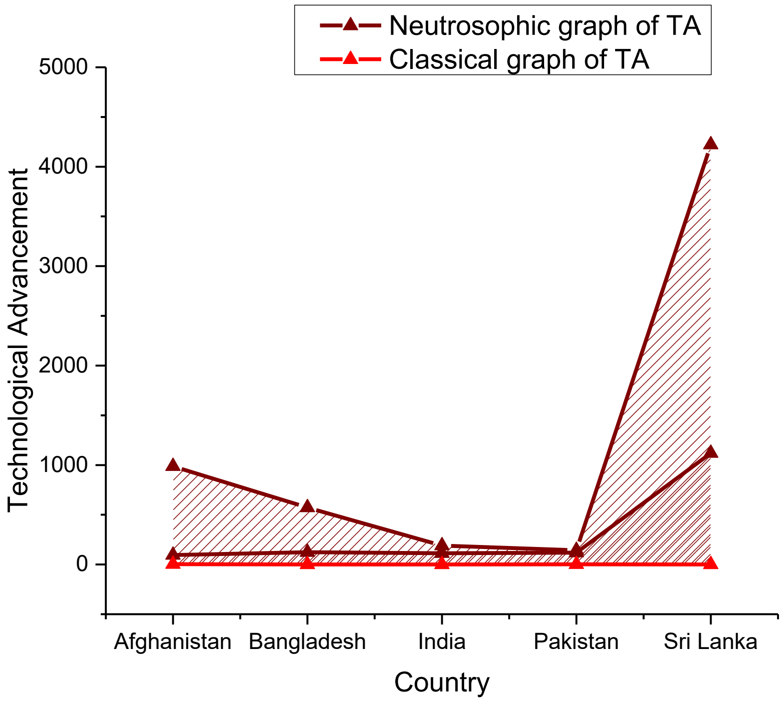


Figure 8: Graphical Representation of Technological Advancement



The graphical comparison between classical and neutrosophic analysis is displayed in Figure 2-8. In Figure 2, the values of the neutrosophic indeterminacy interval are represented by red dotted lines, whereas black lines indicate fix point classical analysis. A similar period of indeterminacy is also seen in Figures 2-8. Graphs of neutrosophic analysis are more flexible and illuminating, as we can see. Therefore, for the agricultural crops yields and productivity, we employed the neutrosophic technique.

4.4 Robustness check

For the robustness checked we used Feasible Generalized Least Squares regression (FGLS). The results of FGLS regression confirming the results of main regression as show in table 6.

Table17: FGLS Regression

logcp	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
logce	.029	.005	5.79	0	.019	.039	***
logfs	.886	.037	23.85	0	.813	.959	***
logcf	-.018	.015	-1.26	.206	-.047	.01	
logfl	-.037	.011	-3.51	0	-.058	-.016	***
logta	-.014	.01	-1.40	.16	-.033	.005	
logrw	.022	.007	2.91	.004	.007	.036	***
Constant	.321	.075	4.30	0	.175	.468	***

*** *p*<.01, ** *p*<.05, * *p*<.1

5. Research Results

The study demonstrates how food security in South Asia depends upon the relationship between agricultural productivity and carbon emission factors and changing climatic patterns. Research shows stable food production (logfs) creates the most significant positive impact on agricultural productivity (logcp). The results demonstrate an effect of 0.871 ($p < 0.01$). According to Godfray et al.[30] sustainable agriculture stands as a central requirement for sustainable food security given the climate changes affecting our world. The negative effect of farmer livelihoods (logfl) on productivity might stem from smallholder farmers' access limitations to resources and technology according to Pretty[36]. The data shows a small and statistically significant relation between Corbin emissions and yield performance (Coef. = 0.026, $p < 0.01$) despite being an inherent aspect of modern farming practices. The study employs two analytical approaches: classical and neutrosophic analysis. The data reduction technique of classical analysis replaces interval-based information with single-point estimates to provide a basic but restrictive understanding. The classical analysis method in India shows crop productivity as 88.3 but the neutrosophic approach reveals much broader variation ($60.9 + 115.7I_{\tilde{CP}}$, $I_{\tilde{CP}} \in [0, 0.473]$). The methodological shortcoming matches Smarandache's[40] assessment against classical analysis since it dismisses uncertain elements and variability that appear in actual data sets. Neutrosophic analysis displays an enhanced view of data intervals since it keeps the original range of variable operations. The expression of CO_2 emission data in Afghanistan incorporates a wide range of variability through $1089 + 11962I_{\tilde{CE}}$ (where $I_{\tilde{CE}}$ falls within the interval [0, 0.908]).

Neutrosophic analysis proves superior for handling uncertain and variable data, especially when analyzing agricultural systems exposed to climate change and emissions, according to the results from both methods. The graphical displays (Figs. 2–8) demonstrate that neutrosophic analysis demonstrates (red dotted lines) the complete varying data scope, but classical analysis gives (black lines) single-point outcomes. Policy decisions require neutrosophic outcomes because these results provide realistic solutions that integrate information about the unpredictable characteristics of climate and emission data. The neutrosophic method shows technological advancement (TA) in Sri Lanka exists between 1119.42 and 4221.35 whereas classical analysis provides a singular value (2670.385).

The results match findings presented in Lobell et al.[10] about crop yield sensitivity to climate fluctuations as well as Pathak et al.[41] who linked agricultural emission to environmental deterioration. This study applies neutrosophic analysis to combine environmental data findings, which provides improved knowledge on how various factors affect South Asian agricultural outcomes. More extensive studies in this field should adopt more socio-economic elements or conduct comprehensive examinations of regional adjustments to climate change. The research demonstrates that flexible data-oriented methods including neutrosophic analysis must be utilized to solve sophisticated agricultural problems which affect climate-sensitive areas.

6. Linkage between empirical results and practical policy recommendations

The empirical results of this study reveal crucial insights for shaping sustainable agricultural policies in South Asia. The strong positive effect of food security on crop productivity underscores the need for robust food systems that are both resilient and inclusive. Governments should prioritize investments in public distribution networks, storage infrastructure, and the promotion of climate-resilient crops. At the same time, the negative impact of farmer livelihoods on productivity highlights persistent structural inequalities in access to land, finance, and technology. Policies must therefore aim to enhance rural credit access, secure land tenure, and expand training programs to empower smallholder farmers, especially those in resource-constrained communities. A targeted approach that strengthens rural institutions and ensures equitable access to agricultural services can significantly improve productivity outcomes.

Additionally, the findings show a statistically significant but modest positive correlation between emissions and productivity, suggesting a reliance on emission-intensive agricultural inputs like chemical fertilizers. To ensure long-term sustainability, this relationship must be addressed through a transition to low-carbon agricultural technologies, such as organic inputs, precision farming, and efficient irrigation systems. Furthermore, the weak impact of climate and technology variables on productivity points to the urgent need for context-specific adaptation strategies and better integration of technological solutions. Policymakers must also invest in advanced data systems—like neutrosophic modeling—to better capture environmental uncertainty and variability. Regional collaboration remains vital; shared emission management, cross-border research, and cooperative food security strategies will enhance South Asia's ability to build climate-resilient agricultural systems.

7. Socio-Economic Review and Policy Implications

The governments of South Asia need to focus on creating food safety through sustainable farming practices which involve sustainable cropping systems along with effective resource management strategies to minimize the negative impacts of emissions and climate change. Research emphasizes how South Asia requires immediately implemented coordinated policies that handle agricultural productivity together with climate resilience and food security issues. The development of climate-smart agriculture needs immediate support by governments through their implementation of precise farming systems together with organic methods and their investment into drought-resistant crops combined with efficient agricultural water distribution systems for adapting to unpredictable rainfall conditions. The development of farmer livelihoods depends equally on improving access to credit in combination with technology and training programs which boost adaptive farming capacity. New social protection systems that include crop insurance and income development programs should be developed to shield farming communities that are at risk due to climate changes. The efforts should receive support from data systems which have advanced analytical methods including neutrosophic modeling to understand natural climate and agricultural system uncertainties.

Regional organizations need to work in unison because they face cross-border climate challenges while attempting to maximize their shared resources. South Asian countries need to develop joint systems which enable sharing of warning systems platforms and emission reduction plans and sustainable farming methodologies. Food security policies need to advance production-centered measures by using methods that include better public distribution system modernization and promoting high-nutrient value crops. The region should implement a comprehensive policy method that equitably combines productivity with sustainability to construct weather-resistant agricultural systems which provide nutrition security for their expanding population. The stability of South Asian agriculture depends heavily on executing both urgent short-term adaptations while conducting slow-paced systemic changes.

8. Conclusion

This study employed Neutrosophic Logic for analyzing food security and agricultural productivity in South Asian Countries. A multifaceted analysis that combines different interconnected factors helps this research to produce knowledge that can contribute to the development of sustainable agricultural methods, protecting food security while enhancing economic strength in the region. The first part of this article focused on the introduction of the title and variables; after that literature review and theoretical justification for this study were discussed in detail. In the next section authors focused on methodology, and after that, analysis was conducted as per the methodology defined, i.e., Classical Analysis and Neutrosophic Analysis. In the next section, empirical results along with practical policy recommendations and socio-economic review with policy implications were discussed.

The research demonstrates a detailed connection between farm output and Corbin emission factors and environmental elements in South Asia, where food security remains the fundamental element supporting agricultural yields. The scholar's research demonstrates the challenging environment facing this region through the negative outcomes for farmers combined with small yet crucial emission implications. Neutrosophic analysis triumphs over classic methods because it recognizes and models various data elements as well as uncertainties for better agricultural research frameworks. Neutrosophic analysis employs indeterminacy models which provide essential insights into climate and emission-related variables because of their unpredictability. Through this method higher academic knowledge takes shape at the same time as managers gain practical wisdom for developing sustainable agricultural solutions.

The study's neutrosophic logic-based approach effectively captures the variability and uncertainty inherent in agricultural data from South Asia, but scaling this methodology for larger datasets requires addressing key computational challenges. To enhance robustness, parallel processing frameworks like Apache Spark can be employed to handle high-dimensional data efficiently, while dimensionality reduction techniques such as PCA can streamline analysis by eliminating redundant variables. Additionally, GPU acceleration and precomputed lookup tables can optimize the iterative calculations involved in neutrosophic interval analysis, ensuring the model remains computationally feasible even as dataset sizes grow. These improvements will allow the methodology to maintain its precision and flexibility while accommodating broader applications, such as multi-country or real-time climate-impact assessments. For policymakers, integrating the enhanced neutrosophic model into decision-support systems (DSS) with interactive dashboards can bridge the gap between empirical results and actionable strategies.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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