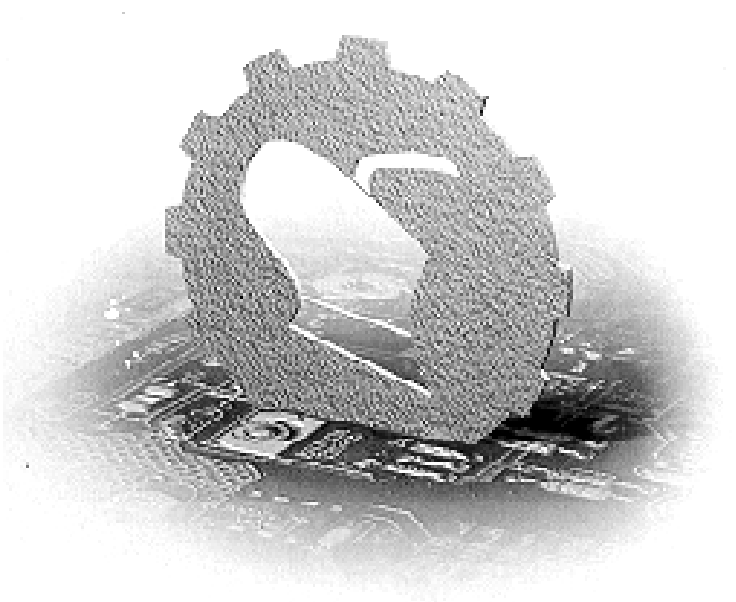
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S A D R Ž A J

EFEKTI KREDITA KOMERCIJALNIH BANAKA NA RAST POLJOPRIVREDNE PROIZVODNJE U NIGERIJI (1980–2022)
Ahmed Olugbenga Busari, Kolapo Kazeem Olalekan, Timothy Olusola Agboola, Tomiwa Peter Adebisi, Uthman Adewale Azeez, Faith Adedayo Adeyemi
DOI: 10.5937/POLJTEH2602001O ..... **1 - 11**

KARAKTERISTIKE RADIO, AUDIO I TEKSTUALNIH KANALA DISTRIBUCIJE EFIKASNIH SERVISNO KLIMATSKIH INFORMACIONIH USLUGA ZA POLJOPRIVREDNIKE U KENJI I ETIOPIJI
Oladimeji Idowu Oladele
DOI: 10.5937/POLJTEH2602012I ..... **12 - 25**

UTICAJ KORIŠĆENJA ZEMLJIŠTA I KLIMATSKIH PROMENA NA PARAMETRE ZEMLJIŠTA U NEKIM ODABRANIM LOKALNIM SAMOUPRAVAMA JUGOISTOČNE NIGERIJE, PRIMENOM SWAT MODELA
Orji Francis N., Erokare E.T., Esokawu Joy, Orji Kalu, Okolocha C. Daniel
DOI: 10.5937/POLJTEH2602026F ..... **26 - 38**

ZNAČAJ FINANSIJSKI OPTIMALNE NABAVKE POLJOPRIVREDNE MEHANIZACIJE U SREDNJIM POLJOPRIVREDNIM PREDUZEĆIMA
Jelena Lutovac, Miloš Lutovac
DOI: : 10.5937/POLJTEH2602039L ..... **39 - 45**

KREDITIRANJE POLJOPRIVREDNE MEHANIZACIJE SA ILI BEZ PODRŠKE IT U PRIPREMI DOKUMENTACIJE ZA POSLOVANJE U SREDNJIM POLJOPRIVREDNIM PREDUZEĆIMA
Slobodan Popović, Jovana Gardašević, Dejan Sredojević, Ivan Arnautović, Milan Radaković, Ivan Pajović, Aleksandra Brakus
DOI: 10.5937/POLJTEH2602046P ..... **46 - 52**

PROCENA REFERENTNE EVAPOTRANSPIRACIJE U BASENU REKE BENIN-OVENA KORIŠĆENJEM PRISTUPA DUBOKOG UČENJA: - PREGLED
Precious O. Ehiomogue, Abdulgafar Usman, Raymond Ekemube, Femi Alao
DOI: 10.5937/POLJTEH2602053E ..... **53 - 63**

UPRAVLJANJE SREDNJE VELIKIM POLJOPRIVREDNIM PREDUZEĆIMA I NABAVKOM MEHANIZACIJE: -UTICAJ SVEOBUHVATNE NASPRAM DELIMIČNE PODRŠKE IT SISTEMA
Čolović Mrđan, Laković Duško, Sredojević Dejan, Arnautović Ivan, Popović Slobodan
DOI: 10.5937/POLJTEH2602064M ..... **64 - 70**

KRITIČKI PREGLED PRIMENE ANALIZE GLAVNIH KOMPONENTI U ISTRAŽIVANJU ZAGAĐENJA PODZEMNIH VODA U NIGERIJI
Precious O. Ehiomogue, Abdulgafar Usman, Femi Alao, Raymond Alex Ekemube
DOI: 10.5937/POLJTEH2602071E ..... **71 – 84**

C O N T E N T

EFFECTS OF COMMERCIAL BANKS' CREDIT ON AGRICULTURAL OUTPUT GROWTH IN NIGERIA (1980-2022)
Ahmed Olugbenga Busari, Kolapo Kazeem Olalekan, Timothy Olusola Agboola, Tomiwa Peter Adebisi, Uthman Adewale Azeez, Faith Adedayo Adeyemi
DOI: 10.5937/POLJTEH2602001O ..... **1 - 11**

FEATURES OF RADIO, AUDIO, AND TEXT-BASED DISSEMINATION CHANNELS FOR EFFECTIVE CLIMATE INFORMATION SERVICES AMONG FARMERS IN KENYA AND ETHIOPIA
Oladimeji Idowu Oladele
DOI: 10.5937/POLJTEH2602012I ..... **12 - 25**

IMPACT OF LAND USE AND CLIMATE CHANGE ON SOIL PARAMETERS IN SOME SELECTED LGA IN SOUTH EASTERN NIGERIA USING SWAT MODEL
Orji Francis N., Erokare E.T., Esokawu Joy, Orji Kalu, Okolocha C. Daniel
DOI: 10.5937/POLJTEH2602026F ..... **26 - 38**

THE SIGNIFICANCE OF THE FINANCIAL OPTIMAL PURCHASE OF AGRICULTURAL MECHANISM IN MEDIUM-SIZED AGRICULTURAL ENTERPRISES
Jelena Lutovac, Miloš Lutovac
DOI: 10.5937/POLJTEH2602039L ..... **39 - 45**

CREDIT FOR AGRICULTURAL MACHINERY WITH OR WITHOUT IT SUPPORT IN THE PREPARATION OF DOCUMENTATION FOR MEDIUM-SIZED AGRICULTURAL ENTERPRISES
Slobodan Popović, Jovana Gardašević, Dejan Sredojević, Ivan Arnautović, Milan Radaković, Ivan Pajović, Aleksandra Brakus
DOI: 10.5937/POLJTEH2602046P ..... **46 - 52**

REFERENCE EVAPOTRANSPIRATION ESTIMATIO IN BENIN-OWENA RIVER BASIN USING DEEP LEARNING APPROACHES: A REVIEW
Precious O. Ehiomogue, Abdulgafar Usman, Raymond Ekemube, Femi Alao
DOI: 10.5937/POLJTEH2602053E ..... **53 - 63**

MANAGING MEDIUM SIZED AGRICULTURAL ENTERPRISES AND MACHINERY PROCUREMENT: -THE IMPACT OF COMPREHENSIVE vs PARTIAL IT SYSTEM SUPPORT
Čolović Mrđan, Laković Duško, Sredojević Dejan, Arnautović Ivan, Popović Slobodan
DOI: 10.5937/POLJTEH2602064M ..... **64 - 70**

A CRITICAL REVIEW OF PRINCIPAL COMPONENT ANALYSIS OF GROUNDWATER CONTAMINATION IN NIGERIA
Precious O. Ehiomogue, Abdulgafar Usman, Femi Alao, Raymond Alex Ekemube
DOI: 10.5937/POLJTEH2602071E ..... **71 – 84**

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EFFECTS OF COMMERCIAL BANKS' CREDIT ON AGRICULTURAL OUTPUT GROWTH IN NIGERIA (1980-2022)

Ahmed Olugbenga Busari[1], Kolapo Kazeem Olalekan [2], Timothy Olusola Agboola[1], Tomiwa Peter Adebisi[1], Uthman Adewale Azeez[1], Faith Adedayo Adeyemi[1]

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Abstract: The study investigates the influence of commercial bank loans on the growth of Nigeria's agricultural output from 1980 to 2020, utilizing annual time series data obtained from the Central Bank of Nigeria (CBN) and FAO Statistics (FAOSTAT). The data analysis involved descriptive statistics including average growth rates, means, standard deviation, coefficients of variation, and percentages. To assess the stationarity of the time series data, the Augmented Dickey-Fuller statistics were applied, while Johansen's method helped confirm co-integration among variables. The study employed the vector auto regression (VAR) method to explore the relationship between bank loans and agricultural output. Throughout the period, both agricultural output and commercial bank credit exhibited fluctuations, largely influenced by public spending trends. The VAR analysis revealed that public spending positively impacts agricultural output, while the interest rate on agricultural loans and bank lending to the agriculture sector show a one-year lag effect.
Collectively, the findings suggest that enhancing budgetary allocations and increasing commercial banks' lending to agriculture can significantly promote agricultural productivity in Nigeria.

Key words*: Agricultural output, Agricultural sector, Agricultural spending, Co-integration analysis, Vector auto regression, Nigeria*

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INTRODUCTION

Agriculture's contribution to human development cannot be overstated. It is the main occupation of the working population, particularly in agrarian countries; it is an essential part of the people's way of life, culture, and customs; and it includes providing the basic food needs of human populations [1].. The most important economic sector in Nigeria is agriculture. Most rural households in the nation rely on it for their livelihoods due to its economic activity [2]. According to [3], the sector is extremely advantageous to the economy because it creates jobs and food, contributes significantly to the GDP, supplies raw materials for related agricultural sectors, and produces agricultural export commodities that provide foreign exchange profits. Historically, commercial banks have been crucial to the financing of agriculture. Commercial banks are interested in lending money to their large client base while keeping in mind the three guiding principles of profitability, liquidity, and solvency. Nonetheless, a number of elements, including the current interest rate, deposit volume, amount of domestic and international investment, bank liquidity ratio, prestige, and public recognition, are taken into consideration when a commercial bank decides whether to make a loan [4]. The inability to obtain financing from commercial banks to enable them to take advantage of economic possibilities to raise their level of output and escape poverty is one of the factors contributing to the decline in the agricultural sector's share of GDP. For many years, rural residents and impoverished farmers have been hampered by credit constraints, which were once considered to be an essential component of a set of inputs required to increase agricultural output. The majority of farmers do not have access to formal loans, which has remained a barrier to their adoption of agricultural innovations and productivity gains.

Despite the significance of finance in agricultural output, there are several issues with both obtaining and repaying it. Institutional issues have not been sufficiently addressed, such as the lending requirements that restrict investors' access to credit facilities. Farmers' capacity to obtain the best possible loan is influenced by a wide range of socioeconomic conditions. These variables include the geography, the age of the farmers, the high interest rate that financial institutions demand, and the danger of loan default [5]. One of the biggest obstacles to the agriculture sector's contribution, according to [6], is funding. Since agricultural credit is a crucial component of agricultural modernization and the commercialization of the rural economy, policy concerns for agricultural productivity have been hampered by the shortage of credit supply and declining government spending on agriculture. Introducing simple and affordable finance is the fastest approach to increase agricultural output. Consequently, meeting the credit needs of the farming community has emerged as the top priority for every succeeding administration [7].

Farmers' access to credit for agricultural investment, which is crucial, is restricted, despite the fact that successive governments have launched and implemented a number of programs to address the issue of agricultural output not being able to meet the nation's demand for agricultural products because of credit shortages [8].

[9] state that it is well established that sufficient funding is necessary for every industry to develop successfully. In order for the economy's agriculture sector to grow, credit is crucial.

The agriculture industry is more reliant on credit than any other sector of the economy because of the seasonal fluctuations in farmer returns and the shift from subsistence to commercial farming [10].

Appropriate financial policies and supportive institutional financing for both commercial and subsistence farming have the potential to boost agricultural development, which will raise the sector's employment and foreign exchange earnings as well as the income of economic actors involved in agricultural activities [11].

The National Accelerated Food Production Program, which was established in 1972, the Agricultural Development Program, which was established in 1975, and Operation Feed the Nation, which was established in 1976, are just a few of the early agricultural policies that the government has established and implemented since the 1970s. Many of these policies were short-lived and failed to meet their goals. Inadequate funding has been found to be a significant barrier to the agricultural sector's growth in the majority of developing nations, including Nigeria [12]. The sector has been clearly characterized by the employment of antiquated and primitive tools as well as inadequate agricultural infrastructure, including inadequate transportation facilities. These terrible traits are thought to be caused by a lack of funding for the purchase of new and improved farming equipment, innovative farming techniques, and enhanced infrastructure. A system of sustainable agricultural financing schemes, programs, and institutions that can offer credit facilities to agricultural producers, processors, and marketers at all levels is what the government has been aiming for since the 1970s because it recognizes this limitation [13]. Despite the implementation of many policies and plans by the government and other institutions to expand the framework of sustainable growth, the agriculture sector continues to operate below ideal levels [14] and [15].

Therefore, from 1980 to 2022, the study looked at how Nigerian agricultural output growth was impacted by commercial banks' lending. The study's primary goal is to investigate how Nigerian agricultural output growth is impacted by commercial banks' loans between 1980 and 2022. The study specifically looks at the trends in government spending, agricultural output growth, and commercial bank credit to the agricultural sector. It also figures out how commercial bank credit affected Nigeria's agricultural output growth from 1980 to 2022.

MATERIAL AND METHODS

Study area

The study was conducted in Nigeria, one of Africa's largest nations, which is located entirely in the tropics along the Gulf of Guinea on the continent's western coast. Between latitudes 4° 16'N and 13° 52' N and longitudes 2° 49' E and 14° 37' E is where Nigeria is located. As of 2016, its estimated population was approximately 170 million, and its total land area was 923,768, 622 km2 (NPC, 2016). The climate is tropical, with high temperatures and humidity as well as distinct wet and dry seasons, notwithstanding the contrasts between the North and the South.

Rainfall overall declines northward from the shore. Rainfall in the extreme north ranges from 500 to 1000 mm per year, whereas in the south, below Latitude 8° N, it ranges from 1,500 to 4,000 mm. In Nigeria, food production is essentially dependent on rainfall. According to Oladimeji and Abdulsalam (2014), Nigeria's irrigated land as a percentage of its total agricultural area is projected to be at 2%, which is less than the average of just 6% for Africa, 37% for Asia, and 14% for Latin America.

Data collection

This study's data came from annual time series. The Central Bank of Nigeria (CBN) publications and the Food and Agriculture Organization (FAO) Statistics (FAOSTAT) were among the secondary sources from which the data sample was gathered. The study specifically gathered information on government spending, interest rates, agricultural credit, agricultural output, and commercial banks' lending to the agricultural sector interest rates expressed as percentages, agricultural credit expressed in billions of Naira, government spending expressed in billions of Naira, and agricultural output growth expressed as percentage changes are the study's independent variables. The study's dependent variable is agricultural output growth, which is defined as the annual increase in output from different agricultural sub-sectors valued in monetary terms.

Data analysis

Several analytical techniques were used in this study, depending on the previously mentioned goals of the study. These consist of average growth rate, means, standard deviation, coefficients of variation, and percentages. These were utilized to explain Nigerian government spending patterns, commercial bank lending to the agricultural sector, and trends in agricultural output growth. The stationarity of time series data was confirmed using Augmented Dickey-Fuller statistics. The co-integration of the model's variables was confirmed using Johansen's approach. The effects of commercial banks' loans on the increase of the agriculture sector's output between 1980 and 2020 were assessed using the Vector Auto Regression Model (VAR). Following, [16], the explicit model that will be used in this study is given as:

$$\ln Y_t=\alpha_1+\alpha_2\ln Y_{t-1}+\alpha_3\ln X_{2t-1}+\alpha_4\ln X_{3t-1}+\alpha_5\ln X_{4t-1}\ u_{t1} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:
Y is the agricultural output growth
X_1 is the government expenditure in billions Naira
X_2 is agricultural credit in billions Naira
X_3 is the commercial banks; lending to agricultural sector in billion Naira
X_4 is the interest rate in the economy measured in percentage.
Ln is the logarithm operator
U_{ts} are stochastic random errors
$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6,$ and λ_1 are parameters to be estimated

The statistical tools (means, standard deviation, coefficients of variation, percentages and average growth rate, Augmented Dickey-Fuller statistics, Johansen's co-integration method, and Error Correction Model) used in this study are justified based on the fact that the study utilised time series data and these tools have been proved in the literature to yield robust estimates from time series data which can be used for policy formulation and forecasting.

RESULTS AND DISCUSSION

Trend in agricultural output in Nigeria (tonnes) (1980-2020)

Table 1 presents a comprehensive overview of Nigeria's agricultural production trends from 1980 to 2022, highlighting a consistent increase in agricultural output throughout this period. The average annual agricultural production was recorded at 8032.01 tons. Notably, the annual percentage change in output was marked by substantial fluctuations, varying between a high of 154.71 percent and a low of 34.03 percent, culminating in an average change of 639.71 percent. Additionally, the coefficient of variation for the entire study period stood at an average of 67.99 percent, illustrating a considerable degree of volatility in agricultural production, with variations ranging from 10.18 percent to 36.23 percent.

Table 1. Trend in agricultural output (tonnes) in Nigeria (1980-2022)

Sub period	Average annual output growth (tonnes)	Annual percentage change	Coefficients of Variation (%)
1980-1989	2697.74	40.669	36.23
1990-1999	3989.92	35.758	10.18
2000-2009	8960.88	154.71	28.47
2010-2022	15711.54	34.03	10.88
All period	8032.01	639.71	67.99

Source: CBN and FAOSTAT, 2024.

Trend in commercial banks' (₦ billions) credit to agriculture in Nigeria (1980-2022)

Table 2 shows the trend of commercial bank lending to the agricultural sector from 1980 to 2022, highlighting an average lending of 133.91 billion annually across the study period. Notably, there was a consistent increase in lending, with an annual change averaging 127.06 percent. This growth varied significantly within sub-periods: it recorded a low of 29.59 percent from 2010 to 2022, while reaching a high of 77.50 percent during 1980-1989. Additionally, the coefficient of variation indicates substantial fluctuation in commercial bank credit within the agricultural sector, ranging from 30.07 percent in the recent sub-period (2010-2022) to a striking 69.29 percent in the earlier one (1980-1989), with an overall average of 138.35 percent throughout the study duration.

Table 2. Trend in commercial banks' (₦ billions) credit to agriculture in Nigeria (1980-2022)

Sub periods	Average commercial banks' (₦ billions)	Annual percentage change	Coefficients of Variation (%)
1980-1989	1.59	77.50	67.29
1990-1999	18.95	63.81	61.11
2000-2009	77.61	23.99	49.35
2010-2022	409.90	29.59	30.07
All period	133.91	127.06	138.34

Source: CBN and FAOSTAT, 2024.

Trends in public expenditure in Nigeria (1980-2022).

Table 3 shows public spending trends over the study period, showcasing a significant increase in average annual public expenditure across different periods. From 1980 to 1989, the average annual public spending was recorded at 17.34 million USD, which escalated dramatically in subsequent decades. In the periods of 1990-1999, 2000-2009, and 2010-2022, public spending rose to 302.08 million USD, 1829.42 million USD, and peaked at 9276.47 million USD, respectively. Notably, the average public spending across the entire study period amounted to 2856.33 million USD.

The data reveals substantial growth rates within each sub-period: 291.51 percent for 1980-1989, 93.64 percent for 1990-1999, 79.70 percent for 2000-2009, and 77.18 percent for 2010-2022, highlighting a trend of increasing expenditure. The overall average annual growth rate for public spending during the study was notably high at 99.94 percent. Furthermore, the coefficients of variation for public spending indicated considerable variability, ranging from 169.99 percent to 170.64 percent, with an average of 61.42 percent throughout the studied period, underscoring the stability of public funding growth. Overall, the findings conclude that public spending has generally increased at an accelerating rate, reflecting ongoing investment trends over the decades.

Table 3. Trend in public expenditure in Nigeria (1980-2022)

Sub-periods	Average public expenditure (‘000 USD) per annum	Annual Percent growth	Coefficients of variation (%)
1980-89	17.34	291.51	169.99
1990-99	302.08	93.64	111.47
2000-09	1829.42	79.70	192.33
2010-2022	9276.47	77.18	170.64
All Period	2856.33	99.94	61.42

Source: Computed from CBN and FAOSTAT, 2024

Unit root test

The analysis presented in Tables 4 and 5 explores the results of unit tests on the variables of a model using the Augmented Dickey-Fuller (ADF) technique. In time series analysis, it is crucial to evaluate whether the variables are stationary or contain a unit root. This examination operates under the premise that non-stationary data cannot be utilized in regression analysis due to the potential for false or spurious results. The ADF test assesses both original and first difference values of the model's variables.

According to the methodology of ADF, if the absolute values of ADF statistics fall below the critical values at the 1%, 5%, and 10% significance levels, the null hypothesis—which posits the presence of a unit root cannot be rejected. Conversely, should the ADF statistics exceed these critical thresholds, especially at the 5% level, it indicates that the null hypothesis can be rejected; thus, the time series data is confirmed as stationary and suitable for regression analysis.

The results presented in Table 4 affirm that the absolute values of the ADF statistics for the original values of the variables are all lower than the critical values, indicating the presence of a unit root, thereby rendering these original values unsuitable for regression analysis.

In contrast, Table 5 displays results from the first difference values, where the absolute values of the ADF statistics rise above the critical values at the 5% level, signifying the absence of a unit root. As a result, the first difference values of the variables are deemed appropriate for statistical regression analysis.

Table 4. Result of ADF unit root for variables of the model (original values)

Variables	Test statistics (ADF)	1% critical value	5% critical value	10% critical value	Decision
Y	-0.341	-3.655	-2.961	2.613	Non-stationary
X_1	-1.700	-3.655	-2.961	2.613	Non-stationary
X_2	-1.706	-3.655	-2.961	2.613	Non-stationary
X_3	-1.784	-3.655	-2.961	2.613	Non-stationary
X_4	-2.132	3.668	-2.966	2.616	Non-stationary

Source: Author Computation 2024.

Table 5. Result of ADF Unit root test for variables of the model (first difference values)

Variables	Test statistics (ADF)	1% critical value	5% critical value	10% critical value	Decision
Y	-3.190	-3.622	-2.964	-2.614	I(1)
X_1	-6.230	-3.622	-2.964	-2.614	I(1)
X_2	-4.529	-3.622	-2.964	-2.614	I(1)
X_3	-4.405	-3.622	-2.964	-2.614	I(1)
X_4	-5.267	-3.622	-2.964	-2.614	I(1)

Source: Author Computation 2024.

Lag length selection

In the context of developing a vector auto regression (VAR) or vector error correction (VEC) model, determining an appropriate lag length is crucial. Several criteria are typically utilized to ascertain this lag length, including the Akaike Information Criterion (AIC), the Han-Quick Criterion (HIC), and the Schwarz Bayesian Information Criterion (SBIC). According to the results shown in Table 6, which evaluate lag length selection based on the Final Prediction Error (FPE), AIC, HIC, and SBIC criteria, the analysis indicates that a lag length of 4 is optimal for both VAR and VEC models. This selection enhances the model's accuracy and reliability in capturing the data's temporal dependencies.

Table 6. Selection-order criteria for lag length of the variables of the model

Lag	LL	LR	Df	P	FPE	AIC	HOIC	SBIC
0	-1182.98				5.3e+21	64.2152	64.2919	64.4329
1	-1013.11	339.75	25	0.000	2.1e+18	56.3841	56.8446	57.6903
2	-975.569	75.074	25	0.000	1.2e+18	55.7064	56.5507	58.1011
3	-901.289	148.56	25	0.000	1.0e+17	53.0426	54.2706	56.5257
4	-805.342	191.89*	25	0.000	3.5e+15*	49.2077*	50.8194*	53.7792*

Endogenous: Y, $\ln X_1$, $\ln X_2$, $\ln X_3$, $\ln X_4$; Exogenous: _cons
Source: Author Computation 2024.

Co-integration test

The co-integration test plays a crucial role in time series analysis by identifying long-term relationships among the variables within a model. When establishing a Vector Error Correction Model (VECM), which accounts for both short-term and long-term relationships, it is essential that a long-term relationship exists among the variables. Conversely, if no long-term co-integration is found, a Vector Auto Regression Model (VAR), which focuses exclusively on short-term relationships, is appropriate. This study employs the Johansen co-integration procedures to determine the number of co-integration equations at a 5% significance level, assessing whether the trace statistic falls below the critical value. The study's findings, presented in Table 7, indicate that there are no co-integrating equations present, signifying an absence of long-term correlation among the model's variables. Thus, the VAR model is employed to analyze the short-term associations between these variables.

Table 7. Result of Johansen tests for co-integration among variables of the model

Rank	Panus	LL	Eigen value	Trace statistics	5% critical value
0	42	125.487		60.591	94.15*
1	53	153.390	0.774	51.505	68.52
2	62	163.331	0.416	31.623	47.21
3	69	169.219	0.273	19.848	29.68
4	74	174.398	0.244	9.490	15.41
5	77	177.554	0.157	3.178	3.76
6	78	179.143	0.082		

Source: Author Computation 2024.

Results of short run vector auto regression model (VAR) regression analysis

The analysis of the short-run VAR model yields several significant findings as presented in Table 8. The model's explanatory power is quantified by an R^2 coefficient of 0.671, indicating that the model accounts for 67.10 percent of the variability in the data. The Chi-square value, recorded at 60.733, is statistically significant at the 1% level, confirming that the model demonstrates a good fit. Key results reveal that government expenditure on agriculture and the credit extended by commercial banks to the agricultural sector, both lagged by one year, have positive influences on the agricultural output for the current year. Specifically, these relationships are statistically significant at the 1% level for government expenditure and at the 10% level for commercial banks' credit. Additionally, when evaluating the impact of interest rates, it is found that the coefficient for agricultural loans whose rates are delayed by two years is also positive and reaches statistical significance at the 5% level. This suggests that the current agricultural output is positively affected by loan interest rates from the agricultural loans two years prior. In conclusion, the findings indicate that the current agricultural output is positively correlated with past government expenditure, past commercial bank credit to agriculture, and the loan interest rates over the previous two years, highlighting the importance of these factors in agricultural performance in the short run.

Table 8. Short run vector error correction model regression analysis results

Variables	Coefficient	Stand. error	z value	p-value
LnX_1				
L1	83.625	22.689	3.69	0.001*
L2	-0.735	0.674	-1.09	0.275
Ln X_2				
L1	-32.033	32.964	-0.97	0.338
L2	-0.088	0.352	-0.25	0.804
Ln X_3				
L1	53.5547	34.225	1.56	0.127***
L2	-0.924	9.842	-0.09	0.926
Ln X_4				
L1	78.28184	62.497	1.25	0.219
L2	0.437	0.204	2.14	0.040**
Constant	2445.032	1144.167	2.14	0.040

R^2=0.671, Chi Square= 60.733 P=0.000*
*mean significant at 1% level
**mean significant at 1% level
***mean significant at 5% level
Source: Author Computation 2024

CONCLUSIONS

It is concluded from the findings of the study that government expenditure, commercial bank credits to agricultural sectors, and interest rates on agricultural credit are significant positive determinants of agricultural output growth in the economy, particularly in the short run. To enhance this growth, recommendations are made for increased budgetary allocations specifically aimed at agricultural expenditure, which would help stimulate agricultural output growth. Moreover, it is suggested that commercial banks should provide more favorable credit allocations to the agricultural sectors, offering agribusiness-friendly interest rates to support the farmers and boost overall productivity.

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EFEKTI KREDITA KOMERCIJALNIH BANAKA NA RAST POLJOPRIVREDNE PROIZVODNJE U NIGERIJI (1980–2022)

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Apstrakt: Rad istražuje uticaj kredita komercijalnih banaka na rast poljoprivredne proizvodnje u Nigeriji za period od 1980 do 2020 godine, koristeći godišnje vremenske serije podataka dobijene od Central Bank of Nigeria (CBN) i FAO, Odeljenje za statistiku (FAOSTAT).

Analiza podataka obuhvatila je primenu deskriptivne statistike, uključujući prosečne stope rasta, aritmetičke sredine, standardne devijacije, koeficijente varijacije i procente učešća. Za testiranje stacionarnosti (promena ili ne) vremenskih serija primenjen je Augmentir Dickey-Fuller test, dok je Johansen metoda korišćena za potvrdu kointegracije među varijablama.
U radu je primenjen model vektorske autoregresije (VAR) radi ispitivanja odnosa između bankarskih kredita i poljoprivredne proizvodnje.
Tokom posmatranog perioda, poljoprivredna proizvodnja i krediti komercijalnih banaka pokazivali su oscilacije, koje su u velikoj meri bile pod uticajem trendova javne potrošnje. Rezultati VAR analize ukazuju da javna potrošnja ima pozitivan uticaj na poljoprivrednu proizvodnju, dok kamatne stope na poljoprivredne kredite i bankarsko kreditiranje poljoprivrednog sektora ispoljavaju efekat sa vremenskim zaostatkom od jedne godine.
Sveukupno, rezultati istraživanja, ukazuju da povećanje budžetskih izdvajanja i intenziviranje kreditiranja poljoprivrede od strane komercijalnih banaka mogu značajno doprineti unapređenju poljoprivredne produktivnosti u Nigeriji.

Ključne reči: *poljoprivredna proizvodnja, poljoprivredni sektor, javna potrošnja u poljoprivredi, kointegraciona analiza, vektorska autoregresija, Nigerija.*

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FEATURES OF RADIO, AUDIO, AND TEXT-BASED DISSEMINATION CHANNELS FOR EFFECTIVE CLIMATE INFORMATION SERVICES AMONG FARMERS IN KENYA AND ETHIOPIA

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Abstract: This study examined the features of radio, audio, and text-based dissemination channels for effective This study examined the features of radio, audio, and text-based dissemination channels for effective climate information services among 171 and 360 farmers randomly selected in Kenya and Ethiopia. The findings show that peculiar characteristics of the dissemination channels influenced farmers' reception of the climate information. The results further show differences in the effectiveness of IVR ($t = 4.626$, $p < 0.05$), Radio ($t = 9.097$, $p < 0.05$), newsletters ($t= 6.859$ $p < 0.05$), and SMS ($t = 7.582$ $p < 0.05$). The characteristics of dissemination channels must be properly examined before their deployment in climate service provision.

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Key words*: Climate information, dissemination, channels, Short Message Service (SMS), radio messages, Interactive Voice Response (IVR), and Newsletters*

INTRODUCTION

Farming as a weather-dependent activity has made farmers monitor and observe weather very closely with traditional knowledge and experience to adapt their agricultural practices, however, changing climates are affecting indigenous knowledge practices, because high incidence and frequency of droughts, and floods causing damage to agriculture, human health, and rural livelihoods [1].

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The innovative management of climate risks offers win-win solutions for the improvement of agricultural practices and food security as well as enhancing the resilience of production systems. The prominent innovative management includes the development of new varieties that are early maturing, drought, pest, and disease-resistant. However, the provision of climate information services enables farmers to explore the opportunities of the window of operation available despite the uncertainty of climatic variables if these are known and adequate preparedness made before the onset through a decision support system that superimposes seasonal climate forecasts, weather index, and early warning on the life cycle of crops from pre to post farm operations.

These advisory services are often through agricultural extension services. Farmers' perception that no one source of information is sufficient, [2], has led to them obtaining information from radio, television, extension agents, model farmers, friends, and relatives, and [3] stated that farmers rely on multiple external sources of information because the efficiency of economic activities in agriculture critically depends on the flow of information relating to farming decisions. There exist heterogeneous impacts of access to agricultural information considering different sources and there a is need for region-specific customization of agricultural information [4], while [5] reported that the credibility of information sources, and the usefulness of the information positively and significantly influence farmers' adoption of biofertilizers.

Globally, the rate of transfer is a greater constraint than the non-availability of technologies and low productivity among farmers [6], is associated with poor acquisition and adoption of improved inputs and technology. The timely and relevant information empowers farmers to make the right choices; because information is one of the most vital resources for awareness, knowledge, and power to increase and sustain agricultural production [7].

Information may originate from different sources [8], to assist farmers in accessing, stimulating, acquiring, and analyzing the feasibility and profitability of agricultural enterprises. Climate information helps smallholder farmers for adaptation to weather variability; thus, information must be accessible, credible, timely, and location-specific and eliminate mismatches of services and users' needs [9, 10]. Farmers' resource endowment determines the information channels used [11], while [12] and [13] stated that generated agricultural information must be presented in usable form by end users, and repackaged into audio, text, graphic, image, and video forms. Audio, audio-visual, and graphical formats of information could be made available for the farmers in various agro-enterprises [14]. Many farmers who cannot read, access agricultural information in audio formats such as radio [15]. Due to preferences for audio-based messages and other factors, phone-based voice messages were used to convert text-based information to audio messages [16]. The use of interactive voice response increased awareness and adoption of agricultural technologies [17]. The main reason for using podcasts to learn about farming practices is the ability to multi-task whilst listening [18]. A library of audio messages about diverse agricultural topics, previously recorded by extension agents, researchers, and experienced farmers, can be accessed through telephone calls [19]. The access to automated audio pre-recorded messages reduced the workload of extension agents and increased access to and active engagement with agricultural advice in Tanzania [20].

The provision of audio messages through a hotline is most effective by focusing on knowledge-based interventions without practical demonstration activities [19], however, [21] found that there is an overall low preference for audio media, both radio and podcasts in the communication of information on nature-related topics.

This paper examined the features of dissemination channels for effective climate information services among farmers in Kenya and Ethiopia because a multi-stakeholder approach was used to develop climate information services using Decision Support System (DSS) tools that combined climatic parameters and crop management practices on specific crop yields and subsequently generate climate-smart agro-advisory. This tool integrated data from various types and sources to generate advisories along the life-cycle of crops specifying agronomic practices within a time limit for successful production that maximized the climatic conditions and physiological processes of the crop. The advisories generated were then supplied to farmers and other value-chain actors through Short Message Service (SMS), radio messages, Interactive Voice Response (IVR), and Newsletters). Several interventions in the climate services provision have deployed dissemination channels without adequate examination of the features of the channels. Similarly, several researches have focused on information sources and channels without adequate exploration of the characteristics of the channels used in climate information services. This study determined the features of dissemination channels used for climate information services from farmers' perspectives.

MATERIAL AND METHODS

The study was carried out in Ada'a district and Embu County in Ethiopia and Kenya respectively. These countries are adjacent to each other and have certain similar characteristics running across the countries. Kenya and Ethiopia have diverse topography, rainfall, and temperature, with most of the population in rural areas and engaging in smallholder farming. Kenya and Ethiopia have been experiencing extreme weather events, severe droughts, flooding high incidences. The recurrence and intensity of droughts have also increased with a lot of the populace living on famine relief and aid.

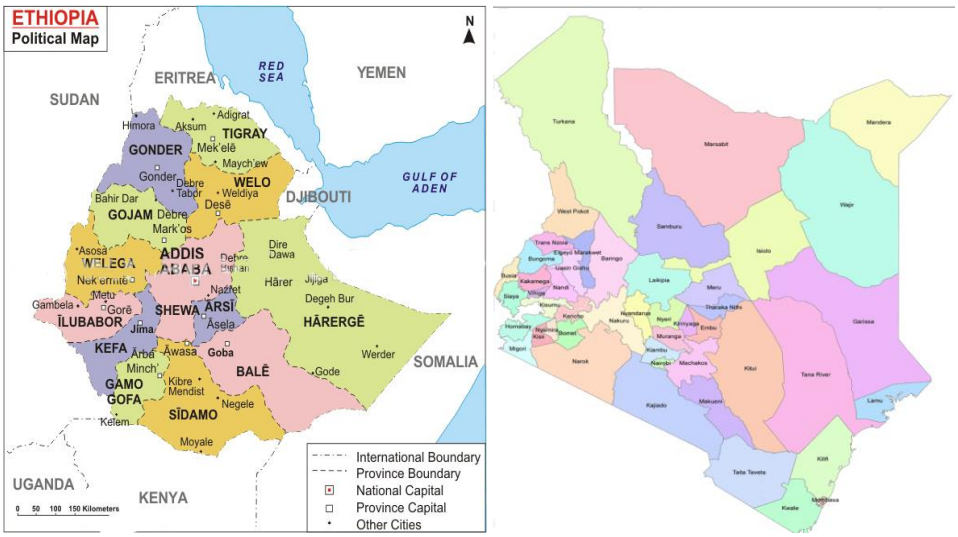


Figure 1. Map of Ethiopia and Kenya showing regions and counties respectively

The low productivity could also be attributed to the degradation of land, poor water management, and low level of technology usage Approximately, 68% of the males were engage in agricultural work compared with 48% of female [22].

The population of the study was all beneficiaries of the agroweather project in Ada'a District and Embu County in Ethiopia and Kenya respectively. The tool covered chickpea, lentils, teff, and wheat farmers in Ethiopia while in Kenya tea, coffee sorghum, and maize and beans farmers. In both countries, farmers were exposed to agricultural radio through local radio services, received bulletins, and newsletters regularly, and enrolled on Ethicom and Safaricom as the internet service provider to offer SMS and interactive voice response services (IVRs) with a total of 1720 and 4500 farmers as sampling frame in Ada and Embu respectively. A simple random sampling was used to select 171 and 360 farmers respectively. Data for the features of Short Message Service (SMS), radio messages, Interactive Voice Response (IVR), and Newsletters as dissemination channels was collected through the use of a structured questionnaire, earlier subjected to face validity among the different national stakeholders. Data was analysed by using the Statistical Package for Social Sciences (SPSS) with frequency counts, percentages used to describe the data, and t-tests to compare farmers' perspectives from the two countries. The model specifications for the t-test is:

$$t = \frac{X_1 - X_2}{\sqrt{\frac{S1^2}{N1} + \frac{S2^2}{N2}}} \quad (1)$$

Where:

X_1 = effectiveness of dissemination channels in Kenya,

X_2 = effectiveness of dissemination channels in Ethiopia,

S_1^2 = variance of X_1 variable,

S_2^2 = variance of X_2 variable,

N_1 = number of farmers in Kenya,

N_2 = number of farmers in Ethiopia.

RESULTS AND DISCUSSION

The results and discussions are organized into two sections on radio, and audio, consisting of radio and interactive voice response and text-based dissemination channels of newsletters and short-message service for effective climate information services among farmers in Kenya and Ethiopia.

Radio

Farmers in Kenya and Ethiopia rate the features of radio as a channel for disseminating climate information on a 28-item 2-point Likert-type scale of Yes (2) and No (1). The prominent features rated by many farmers were: I practice the message from the radio program (57.2), the time of the agricultural radio program is appropriate (60.3), the Agricultural radio program covers climatic elements (57.5), I have learned from the program (76.9), I want the program repeated (64.4).

This result implies that farmers are interested in the use of radio for receiving climate information as they were able to understand the messages.

It also stresses how radio has accomplished the provision of climate information among farmers. Radio is the major channel for accessing climate information [23]. Agricultural producers in Kansas use the Internet, mobile devices, and radio, as well as print and radio sources, to gain climate information [24]. Radio is the most prominent source of information in Africa and its ownership influences weather and climate decision-making in Africa [25], and according to [26], many farmers preferred radio as an important source of information due to the elimination of the literacy challenges. In Southern Ethiopia, radio is widely used to disseminate, technologies, provide market information and announce new varieties [27].

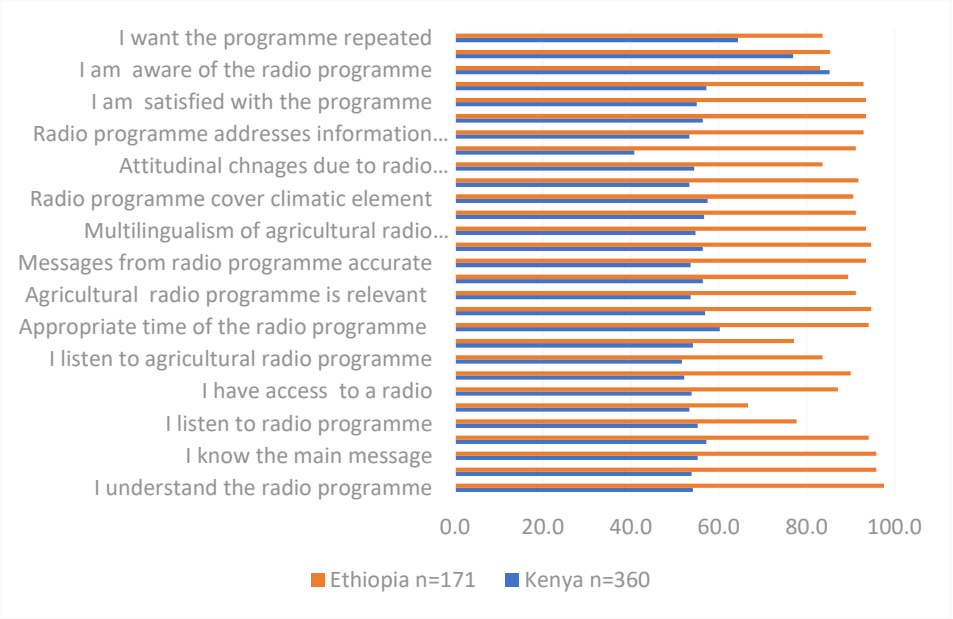


Figure 2. Features of Radio use for climate information among farmers

Interactive Voice Response

Kenyan and Ethiopian farmers' perspectives on the use of interactive voice response for climate information services provision were rated on 25 items using a 2-point Likert type scale of Yes (2) and No (1).
The prominent features rated by the majority of farmers were I am satisfied with calls on IVR (62.5), Calls to IVR are free (64.4), IVR Calls are authenticated (55.6), IVR allows frequent calls (54.4), IVR allows the use of any mobile phone (53.1), there is a lot of errors (97.1%), IVR responds to different topics made by callers at the same time(94.3%), Most queries are abandoned on IVR(97.1%) and Peak voice traffic is very frequent(94.3%).
This result implies that farmers are fascinated by the use of IVR for receiving climate information as they were able to appreciate the messages. It also emphasizes how IVR has fulfilled the role of provision of climate information among farmers.
In Uganda, many farmers used mobile phones to access agricultural inputs and market information [28].

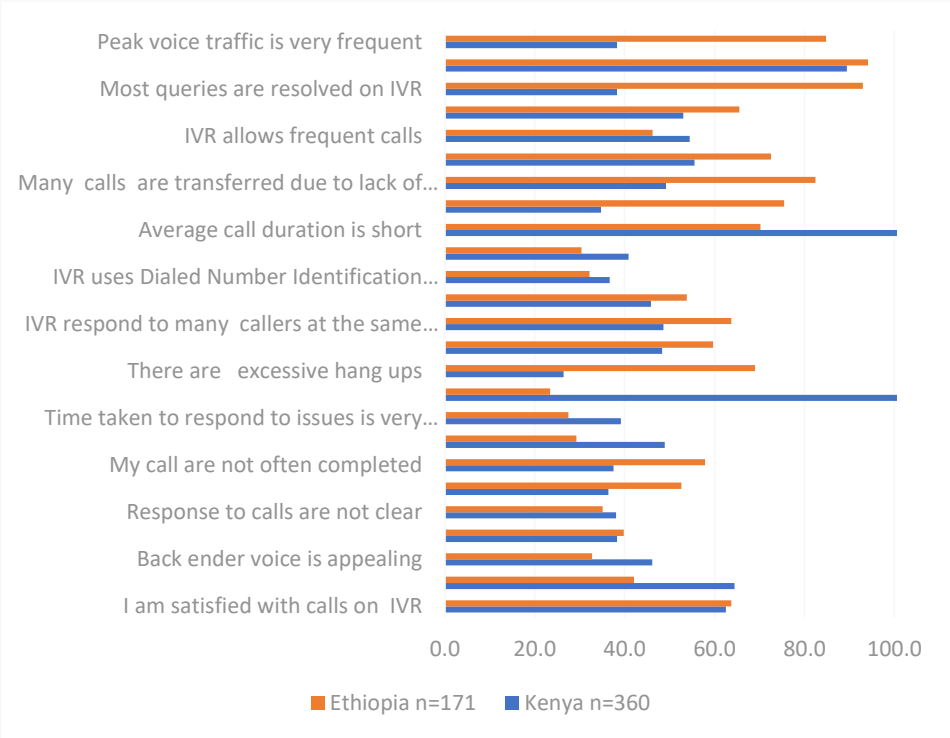


Figure 3. Features of interactive voice response use for climate information among farmers

Short Message Services

In Kenya, farmers rated the features of short message service use for climate information services on 23- items using a 2-point Likert-type scale of Yes (2) and No (1).

The prominent features rated by at least 50 percent of the farmers were Push-type eWarnings SMS (59.7%), Cost of SMS is right (57.2%), SMS is from the reliable source of data (58.3%), SMS gives an accurate source of data (55.6%), I can read SMS (58.9%), I understand SMS (57.0%), The user needs no further information (58.3%). In Ethiopia, farmers' responses were 94.3 percent each for the cost of SMS is right, Period SMS started is adequate, SMS is from a reliable source of data, SMS is timely and SMS is reliable. These results imply that farmers can maneuver the use of SMS for receiving information as they may not encounter many difficulties with the use of SMS. It is also a reflection of how SMS has fared among farmers in its use for the provision of climate information to farmers. Mobile phone-enabled agricultural information provision services have revolutionized agriculture and rural livelihoods in Africa [29] and [30] found that in response to the rapidly expanding demand for information, mobile phone-based weather and market information should be current and provide client-specific information.
Information dissemination through mobile phones is enhanced through cascaded information to farm level, location-specific and reliable forecasts; embedded in existing local networks, use of local language and available channels [31], while [32] indicated that the majority of farmers use SMS for agricultural marketing prices in Karnataka State. The application of internet-based radio and mobile phone systems has revolutionized weather forecast dissemination [33].

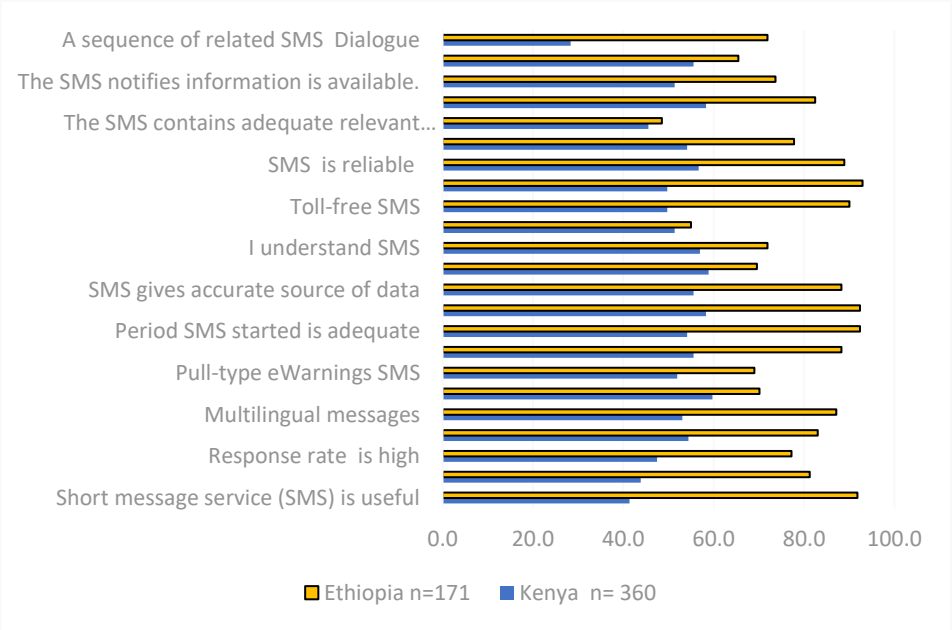


Figure 4. Features of short message service use for climate information among farmers

Newsletters

Farmers' perspectives on the use of newsletters for climate information services provision were rated on 23 items using a 2-point Likert-type scale of Yes (2) and No (1).

The prominent features rated by farmers were my practices have changed due to information in the newsletter (92.22%), farmers of different crops are covered (56.7%), farmers of different age groups are covered (57.2%), male and female farmers are covered (56.9%), many people read a copy of the newsletter (55.8%), the paper has been strong enough to hand around without disintegrating (55%) in both Kenya and Ethiopia. These results imply that farmers are receptive to the use of newsletters for receiving climate information as they can handle and interpret the content. It also echoes how newsletters have performed among farmers in their use for the provision of climate information to farmers. An iterative loop of information products, efficient information delivery, use, and enhanced knowledge would help overcome climate change challenges [34].
The use of newsletters as a dissemination channel promotes the scale and reliability of the source of climate forecasts, which serve as determinants of adoption and [35] found that the Coffee Wilt Programme (RCWP) utilized newsletters in several languages in addition to radio broadcasts to disseminate information.

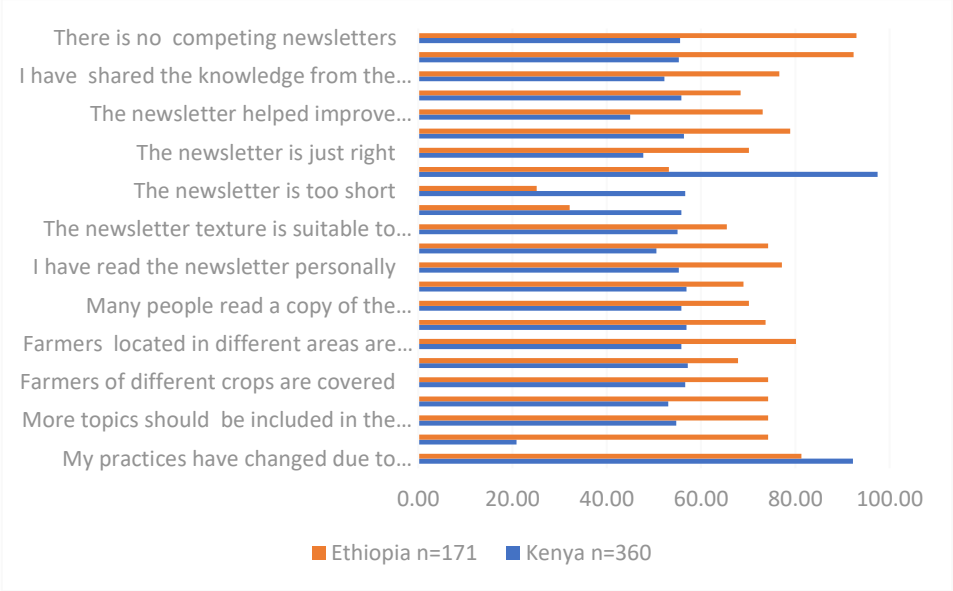


Figure 5. Features of newsletters use for climate information among farmers

Impact of use climate information

The results on the impact of the use of climate information were presented in the figure 6 from Kenya and Ethiopian 2farmers perspectives. The results state that improved use of farm resources (90%), changes in planting practices (85%), changes in harvesting practices (83%) prevention of pest and disease attacks (88%). All the impacts listed received at least an 80% percent positive rating by the farmers, including prevention of crop field losses, improved use of farm resources, prevention of pest and disease attacks, effective utilization of natural resources, increased productivity, environmentally friendly practices, changes in planting practices, changes in weeding practices, changes in harvesting practices and information content are useful.

Farmers' adaptation strategies to climate change include diversifying crops, use of new varieties, and changing the dates of farm operations [36].

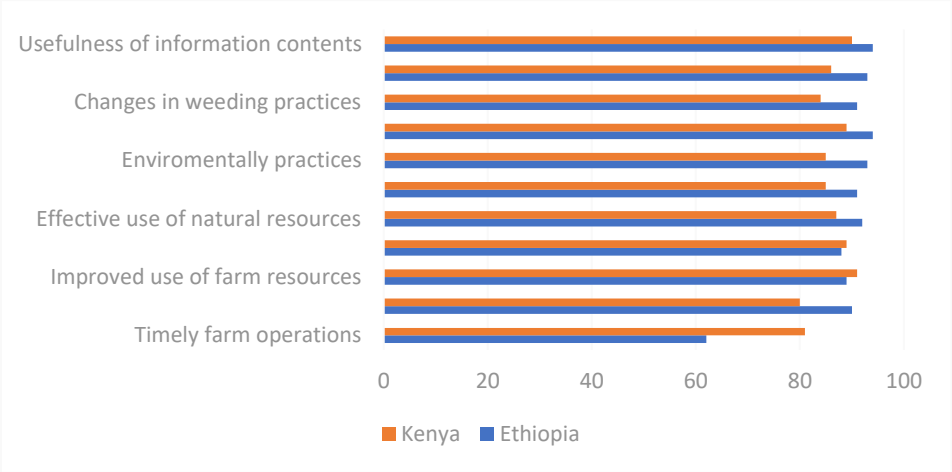


Figure 6. Impacts of climate information

Constraints to the use of climate information

Farmers from Kenya and Ethiopia expressed constraints to the use of climate services with at least 50 percent proportion as technical ability of the farmers, associated cost, availability of inputs Difficulty index, and Time lag of the messages. The constraints indicated by farmers have implications for the nature and level of technical language used on climate messages, and the provision of means or links to credit sources for farmers to be able to afford the associated cost and inputs that will be jointly demanded for the adoption of climate messages. The use of information communication technologies devices enhances delivery and adoption of agrometeorology information [37] and [38] found that poor infrastructure has limited the functionality of ICT in rural areas.

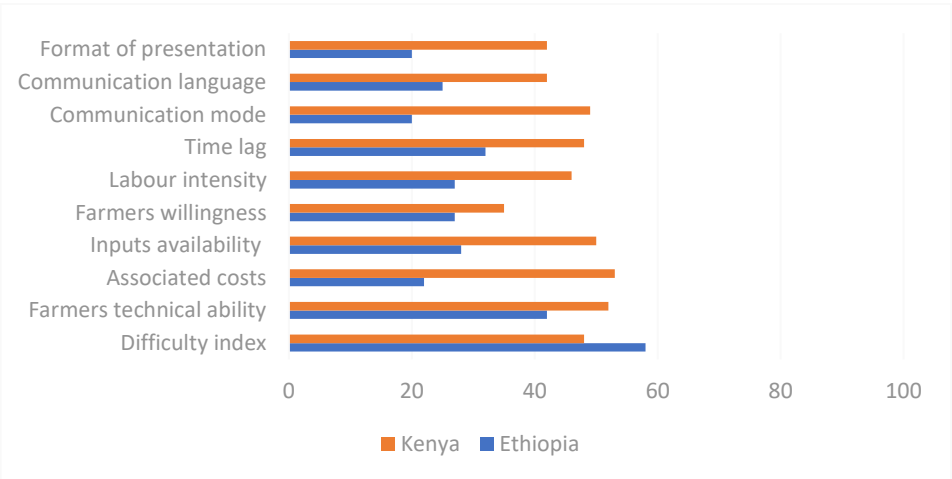


Figure7. Constraints to use of climate information

Table 1. Effectiveness of dissemination channels

	Countr.	N	Mean	Std. Deviat.	Std. Error Mean	t	Df	p	Cohen's d Standard. (Point Estimate)	Hedges' correct. (Point Est.)	Glass's delta (Point Estimate)
IVR	Kenya	25	193.00	98.77	19.75	4.626	48	0.001	74.47 (1.31)	75.66 (1.28)	36.55 (2.66)
	Ethiopia	25	95.56	36.54	7.31						
Radio	Kenya	29	204.13	28.01	5.20	9.097	56	0.001	21.49 (2.39)	21.78 (2.36)	11.78 (4.36)
	Ethiopia	29	152.79	11.78	2.18						
Newsletter	Kenya	23	203.34	51.57	10.75	6.859	44	0.001	41.01 (2.02)	41.73 (1.98)	26.54 (3.12)
	Ethiopia	23	120.39	26.53	5.53						
SMS	Kenya	23	186.60	25.44	5.30	7.582	44	0.001	23.29 (2.24)	23.70 (2.19)	20.93 (2.49)
	Ethiopia	23	134.52	20.93	4.36						
Impacts	Kenya	11	86.09	3.56	1.07	0.93	20	0.183	6.92 (-.39)	7.18 (-.38)	9.10 (-.29)
	Ethiopia	11	88.81	9.10	2.74						
Constra.	Kenya	10	46.50	5.46	1.72	4.00	18	0.001	9.16 (1.79)	9.57 (1.71)	11.75 (1.39)
	Ethiopia	10	30.10	11.75	3.72						

Table 1 presents the results of the comparison of the effectiveness of dissemination channels by farmers from Kenya and Ethiopia. The results show significant differences in the effectiveness of IVR ($t = 4.626$, $p < 0.05$), Radio ($t = 9.097$, $p < 0.05$), newsletters ($t = 6.859$ $p < 0.05$), and SMS ($t = 7.582$ $p < 0.05$). This may be attributed to the timeliness, elimination of message distortion, the scope, coverage, and clarity of messages obtained by farmers through the channels. **F**armers rely on multiple external sources of information because the efficiency of economic activities in agriculture critically depends on the flow of information relating to farming decisions [39], and [40] stressed that there exist heterogeneous impacts of access to agricultural information considering different sources and there is a need for region-specific customization of agricultural information. Farmers in Sri Lanka, information availability is the most important factor for information access, and is followed by social relationships, easy access, distance to agriculture officers and cultural proximity [41]. The adopted technology could not only depend on how efficiently the information flows among farmers, but also on the available information sources [42]. Table 1 further shows that a significant difference exists in terms of the constraints, farmers experience in the use of climate information in Kenya and Ethiopia, whereas no significant difference was recorded for the impacts of climate information between the two countries.

CONCLUSIONS

This paper provides large-scale evidence of the features of dissemination channels for effective climate information services among farmers in Kenya and Ethiopia to facilitate the deployment of appropriate dissemination channels for climate information. The results show that in the use of Short Message Services, cost should be low, content to be adequate, reliable, timely, and in local languages; while newsletter should be illustrative, and the distribution should cover all demographic classes of farmers. Similarly, radio programs on climate information should be on appropriate timing for broadcast and duration, and cover all climatic elements with repeated broadcast; while IVR responds to different topics made by callers at the same time not abandon queries and manage peak voice traffic. Climate information has improved the use of farm resources, changed planting practices, and harvested practices, and prevented pest and disease attacks. The constraints to the use of climate services are farmers' technical ability, associated cost, availability of inputs, messages' difficulty index, and time lag. It was found that significant differences in the effectiveness of IVR, Radio, newsletters, and SMS exist, as well as the constraints farmers experience in the use of climate information whereas no significant difference was recorded for the impacts of climate information between the two countries.

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KARAKTERISTIKE RADIO, AUDIO I TEKSTUALNIH KANALA DISTRIBUCIJE EFIKASNIH SERVISNO KLIMATSKIH INFORMACIONIH USLUGA ZA POLJOPRIVREDNIKE U KENJI I ETIOPIJI

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Apstrakt. Ova studija je ispitivala karakteristike radio, audio i tekstualnih kanala distribucije informacija zbog efikasnog pružanja klimatskih informacionih usluga za uzorak od 171 i 360 nasumično odabranih poljoprivrednika iz Kenje i Etiopije.

Rezultati pokazuju da su specifične karakteristike ovih kanala distribucije informacija uticale na efikasnost prijema klimatskih informacija kod poljoprivrednika.

Rezultati dalje analize pokazuju razlike u efikasnosti IOG (Interaktivni odgovori glasom*, eng.,* IVR-Interactive Voice Response) ($t = 4{,}626$, $p < 0{,}05$), radio emisija ($t = 9{,}097$, $p < 0{,}05$), biltena ($t = 6{,}859$, $p < 0{,}05$) i SMS poruka ($t = 7{,}582$, $p < 0{,}05$).

Karakteristike kanala distribucije informacija moraju biti pažljivo ispitane, pre njihove praktične primene u pružanju klimatskih usluga korisnicima .

Ključne reči: *Klimatske informacije, distribucija, kanali, usluga kratkih poruka (SMS), radio poruke, interaktivni odgovori glasom (IVR) i bilteni.*

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IMPACT OF LAND USE AND CLIMATE CHANGE ON SOIL PARAMETERS IN SOME SELECTED LGA IN SOUTH EASTERN NIGERIA USING SWAT MODEL

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Abstract: The increasing impacts of climate change and land-use alteration have emerged as major environmental challenges affecting soil water quality, agricultural productivity, and ecosystem resilience, particularly in tropical regions. In recent decades, rising global temperatures, irregular precipitation patterns, and unsustainable human activities such as deforestation and intensive cultivation have disrupted the natural hydrological balance, leading to soil degradation, reduced groundwater recharge, and declining water quality.

This study focuses on assessing the effects of climate and land-use changes on soil water content and quality within selected local government areas in southeastern Nigeria using the Soil and Water Assessment Tool (SWAT).
The model was employed to simulate the hydrological responses of different land-use and climatic scenarios on soil moisture, surface runoff, and river discharge within the study area.

This study involved the acquisition and integration of spatial data such as Digital Elevation Model (DEM), soil classification maps, land-use data from Landsat imagery, and climatic data (rainfall, temperature, humidity, and wind speed). These datasets were processed and input into the SWAT model, which was calibrated and validated using observed hydrological data from 2013 to 2023. Calibration and sensitivity analysis identified key parameters influencing the hydrological response, including soil texture, infiltration rate, evapotranspiration, and precipitation intensity.

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Model validation produced acceptable statistical results, demonstrating a satisfactory correlation between simulated and observed values, thereby confirming the reliability of the simulation for predictive analysis. Scenario simulations were conducted to examine the impacts of varying rainfall and temperature levels, as well as different land-use patterns such as partial and complete deforestation, agricultural expansion, and reforestation.

Results from the analysis revealed that increased temperature coupled with reduced rainfall significantly decreases soil moisture, groundwater recharge, and river discharge. Conversely, afforestation and proper land management practices enhance soil water retention, minimize erosion, and stabilize hydrological cycles.

The findings indicated results for absolute values and percentage distributions between 2013 and 2023: Thick Forest 48128.76 (39.712%), Farmland 35001.54 (28.881%), Built-Up/Bare Surface 35237.07 (29.075%), and Water 2826.45 (2.332%). For 2023: Thick Forest 29273.57 (24.237%), Farmland 32031.00 (26.430%), Built-Up/Bare Surface 57268.08 (47.253%), and Water 2521.17 (2.080%).

This research demonstrates the strong interdependence between climate dynamics, land-use patterns, and soil-water systems. The study emphasizes the necessity for integrated watershed management, climate-smart agriculture, and adaptive land-use planning as sustainable strategies for mitigating the adverse effects of climate change.

***Key words**: SWAT, Digital Elevation Model, Land Use Hydrology, Ecosystems*

INTRODUCTION

The impact of climate change on hydrology, ecology and meteorology along with their economic and social relevance is very important in managing water resources, agricultural activities and the ecosystem. Just as there is abundant rainfall leading to abundant surface water, so there is limited rainfall leading to drought, desertification and scarce availability of water resources. The approach to creating a balance between these two extremes is very important [1, 2].

Water is one of the essential commodities on earth that is widely tapped and utilized by man to meet his various needs. Water is an indispensable resource for the welfare of man, animals and plants.

The world is gradually descending into a critical state where water supply is rapidly diminishing and struggles to meet the demand of the increasing population as a result of climate change impact on hydrological processes. Since the last century, the world's population alongside urbanization, industrialization and agricultural production have multiplied exponentially.

This invariably means that the demand for water has drastically increased over the years and the quality of water resources is fast depleting as a result of increased human activities in various sectors [3].

These changes have given room to a wide range of water exploration; both surface water and groundwater. This has created a lot of adverse consequences across different countries in the world. Climate change can cause significant impacts on water resources by influencing the hydrological cycle.

These notable changes in temperature and variations in precipitation have different effects on the quantity and quality of evapotranspiration and runoff components. In other words, the state of water balance can be greatly influenced by climate change resulting in a massive decline in agricultural production, industrialization and urban development [4].

As water demand continues to rise with a potential likelihood where available supply may not meet the demand, it has become very important that adequate management plans be sought and implemented to effectively manage the likelihood of such occurrence. Finding water balance in the ecosystem is an important step in addressing the issue of water resource sustainability. Therefore, the prediction of water balance components is very useful in ensuring food security, preventing land degradation and estimating water availability.

Water resource decision-making has been based traditionally on observed historical events on water availability indicators like river flow volumes, groundwater levels, drought, desertification, etc. and on assumptions of a repetitive future occurrence. That is, the probability distribution of relevant hydro-climatic variables is time-invariant. This argument has since been debated and found to be ineffective in handling issues of water resource management regarding climate change [5].

The World Resources Institute (WRI) projects that by 2025, close to half of the world's population estimated at 3.5 billion could experience water scarcity. The severity of such an occurrence puts the world in a critical state. Africa is a continent of vast land and given to a wide range of climate regimes at varying magnitudes. As the average population continues to increase across the continent, there is a corresponding rise in demand for water as well. According to reports from IPCC [1], the impact of climate change is expected to have varied socioeconomic effects across various countries.

It is projected that most developing countries, especially in Africa will find it very difficult to keep up with its impacts. For example, the recent events of flooding, drought and urban water shortages as well as water pollution – oil spillage and saltwater intrusions in Nigeria clearly highlight the impacts that most of these African countries stand to face and underline the need for a rapid response and rational planning towards mitigating these impacts and consequently ensuring water resources sustainability.

The challenge of uncertainties surrounding climate conditions and the need to identify effective mitigating and adaptive measures have created room for the introduction of various approaches. Hydrological modelling is very critical in nearly every element of water resource management, water quality, climate risk management and advanced detection of hazardous events. Irrespective of these problems that hydrological models try to solve, the issue of forecasting remains a difficult task [6, 7].

Recent years have seen the advancement of hydrological models and the introduction of machine learning techniques to improve the process.

Machine learning programs like adaptive neuro-fuzzy inference systems (ANFIS), support vector regressions (SVR), artificial neural networks (ANN) and genetic programming have been widely adopted in hydrological processes and have shown to be very effective in predicting hydrological processes [8].

Constructing strategies and policies for limiting the effect of climate change on water resources and the environment requires both quantitative and qualitative approaches to effectively implement a hydrological process. Water resource management cannot be treated as a separate entity from the ecosystem.

It is essential to consider the entirety of the system taking into consideration factors like land use management practices, quality and quantity of groundwater and surface water, crop productivity, etc [9].

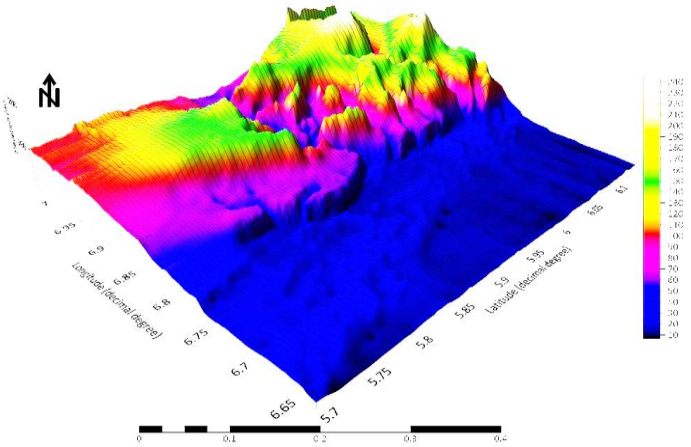
There are several hydrological models fitted to suit specific study objectives. Hydrological models seek to reveal hydrological processes within a catchment and beyond. Soil and Water Assessment Tool (SWAT) models are eco-hydrological models very efficient in assessing hydrological processes as well as simulating crop production and growth within a catchment. Hydrological impacts of climate change are a likely danger to human societal activities as they frequently have serious ramifications for people living near water bodies, agriculture, ecosystems and hydropower production [10].

Thus, the need to provide the necessary information on potential future changes in the hydrological cycle becomes pertinent to enable decision makers to develop possible mitigation and adaptation strategies. Hydrological models are applied to model the impact of climate change on the water cycle as the event happens in real life, also, to forecast the future hydrological system. To drive such a model, reliable hydro-meteorological data such as temperature, precipitation, evapotranspiration, and river discharge are needed [11].

Nigeria experiences various effects of climate change impacts across the country. Hence, it has become very important that efforts to curb climate change impacts as well as credible reports be readily available to help decision policymakers propose effective measures to mitigate the effects of climate change. The lack of credible data in Nigeria currently makes it difficult to effectively quantify the extent of climate change impact in the country. Hence, this research seeks to implement a hydrological model using SWAT models in evaluating the impact of climate change and land use on soil properties in Michael Okpara University of Agriculture, Umudike.

MATERIAL AND METHODS

Michael Okpara University of Agriculture is situated at latitude 5.48°N (5°28′N to 5°30′N) and longitude 7.55°E to 7.56°E, located southeast of Umuahia.



3D Surface Model of the Study Area [Projection: Perspective; Rotation: 45°; Tilt 30°; Field of View 45°]

Fig.1. 3D Surface Model of the Study Area

The SWAT Minimum and Maximum Normalization

The data collected covered a period of 10 years (2013–2023) and included river discharge (m^3/s), rainfall (mm), temperature (°C), and relative humidity (%). These were normalized between the ranges of 0–1 via the min–max method (eq. (1)), to transform the data into a convenient and trainable form before being used for training, testing, and validation for model development.

$$N_k = \frac{R_k - Min_k}{Max_k - Min_k} \quad (1)$$

Where:

- R_k = real value applied to neuron k
- N_k = normalization value calculated for neuron k
- Max_k= maximum number
- Min_k = minimum number
-

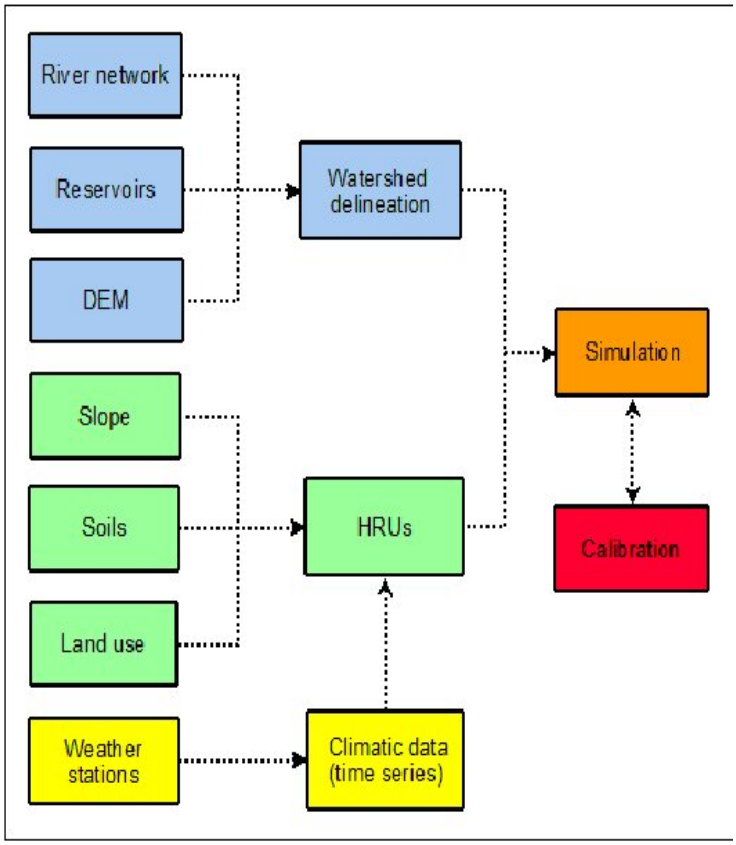


Fig. 2. Classification of SWAT models (Peter et al., 2010)

Indices for the Land Use Cover Characteristics

Table 1. Indices for Land Use/Land Cover Change

S/N	Indices	Definition	Unit of Measurement
1	Water bodies	Areas covered by water, including rivers, oceans, reservoirs, ponds, lakes, streams	Hectare
2	Thick Bush	Land left uncultivated for >5 years; secondary forest	Hectare
3	Cultivated Land	Existing farmland under cultivation	Hectare
4	Fallowed land	Land previously cultivated but left uncultivated for <3 years	Hectare
5	Built Up	Land occupied by buildings/structures	Hectare

The detection of changes provided an understanding of land use/land cover changes occurring in the catchment over years and their possible influence on water flow in the river system.

The land-cover change in percentage was calculated using the equation adapted from Lambin (2011):

$$Percentage\ Change = \frac{OC}{ASC} \times 100 \quad \textbf{(2)}$$

Where:

- OC = observed change
- ASC = absolute sum of change

Annual rate of change was calculated as:

$$Annual\ Rate\ Change = \frac{Y_2 - Y_1}{N} \quad \textbf{(3)}$$

Where:

- N = number of years
- Y_1 = starting year
- Y_2= ending year

Performance Metrics of the Developed SWAT Model

The SWAT model was assessed via metric indicators such as coefficient of determination ((R^2)) and mean square error (MSE).

$$\boldsymbol{R^2 = 1 - \frac{\sum_{i=1}^{n} (Y_{i.pred} - Y_{i.exp})^2}{\sum_{i=1}^{n} (Y_{i.pred} - Y_{exp.ave})^2}} \quad \textbf{(4)}$$

$$\boldsymbol{MSE = \frac{\sum_{i=1}^{n} (Y_{i.exp} - Y_{i.pred})^2}{n}} \quad \textbf{(5)}$$

RESULTS AND DISCUSSION

The performance, in terms of regression value (R) and mean square error (MSE), of the SWAT model developed in this study was compared with the performance of the same model in other fields of study such as extraction, energy, economy, biogas production, and more. This comparison with previous studies was done to examine the reliability of the developed SWAT model for predicting/forecasting, as presented in Table 2.

Table 2. Comparative study of the developed SWAT model with previous work in the literature

Predictive Model	Predicted/Forecasting Output	Performance Metric (R, MSE)	Reference
NARX-NN	River discharge	0.9987, 4.30×10^{-5}	Orji et al., 2024
SWAT	Exchange rate	0.9962, 1.98×10^{-5}	Markova, 2019
SWAT	Rainfall quantities	0.9532, 0.00280	Tawfeeq and Arb, 2016

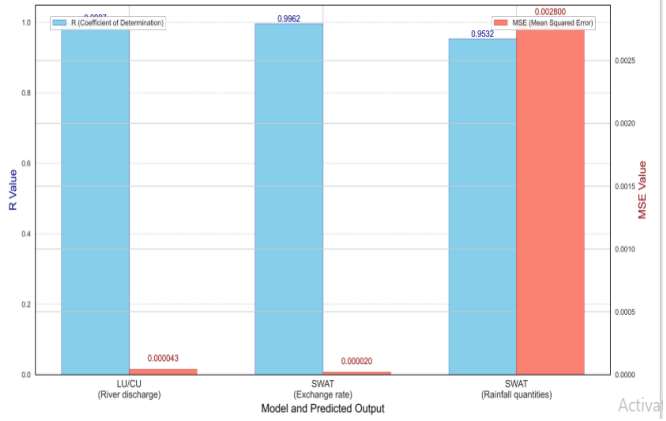


Fig. 3. Performance values for R and MSE of the SWAT model

Impact of Land-Use Characteristics in the Last 10 Years in Response to Climate Change

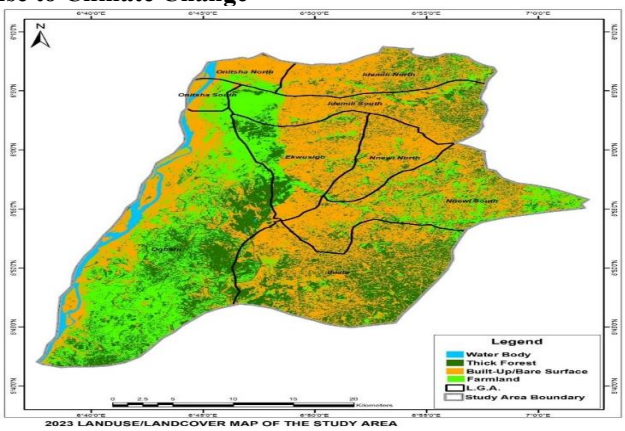


Fig. 4. 2013 Land-Use/Land-Cover Classes (Source: Classified SatelliteImage of Anambra State, 2013)

2013 Land-Use/Land-Cover distribution (absolute values):

- Thick Forest: 48,128.76
- Farmland: 35,001.54
- Built-Up/Bare Surface: 35,237.07
- Water: 2,826.45

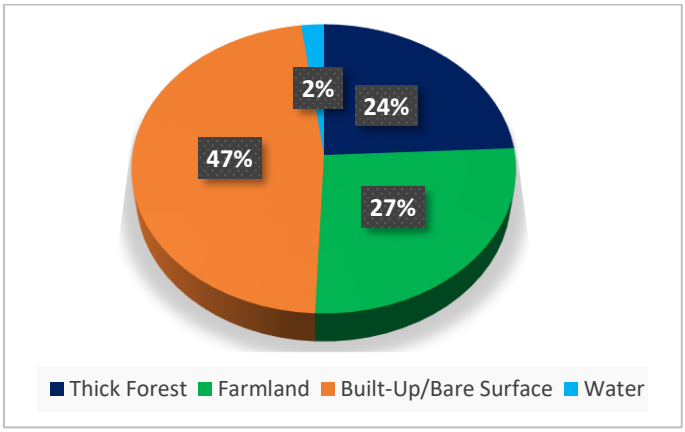


Fig. 5. Pie Chart of 2013 Land-Use/Land-Cover Status
(Source: Digitized data from Satellite Imagery, 2013)

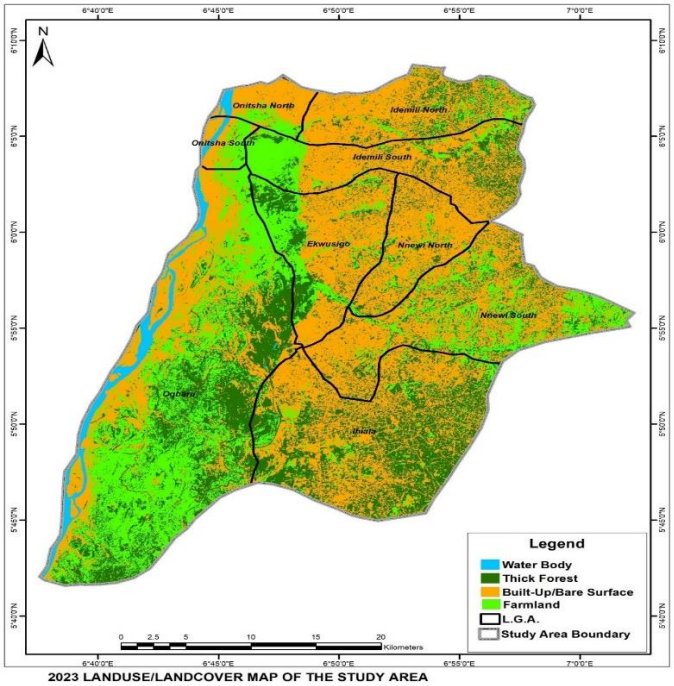


Fig. 6. 2023 Land-Use/Land-Cover Classes
(Source: Classified Satellite Image of Anambra State, 2023)

2023 Land-Use/Land-Cover distribution (absolute values):

- Thick Forest: 29,373.57
- Farmland: 32,031.00
- Built-Up/Bare Surface: 57,268.08
- Water: 2,521.17

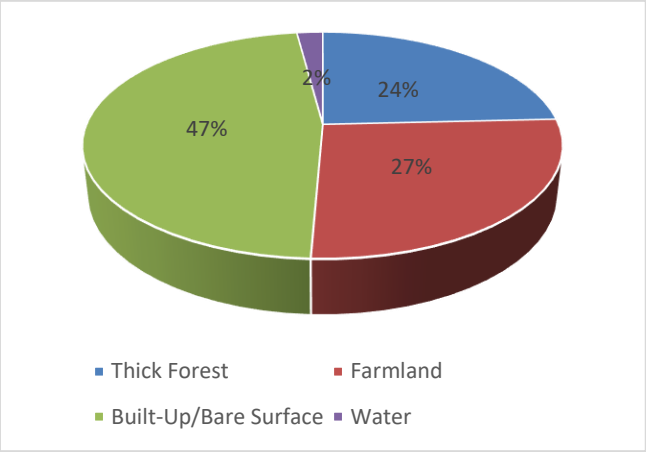


Fig. 7. Pie Chart of 2023 Land-Use/Land-Cover Status
(Source: Digitized data from Satellite Imagery, 2023)

Comparative Land-Use/Land-Cover Status (2013 vs. 2023)

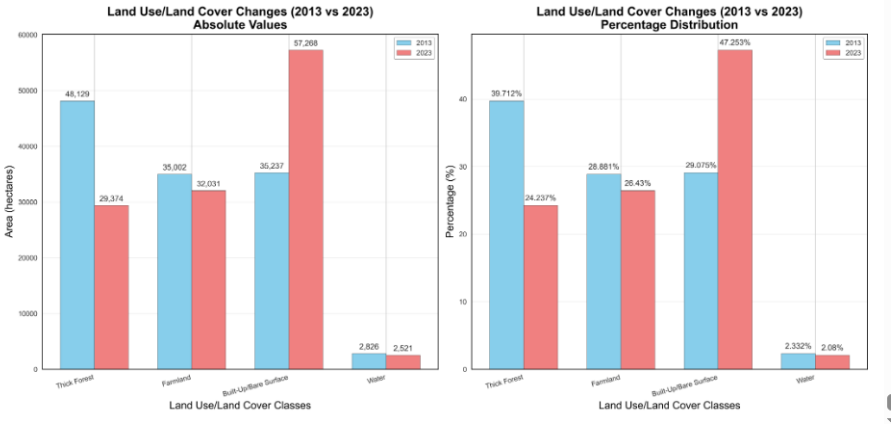


Fig. 8. Bar Chart of 2013 and 2023 Land-Use/Land-Cover Status for absolute values and percentage distribution

SWAT Prediction Pattern on the Soil Properties

The result of the prediction showed that there would be fluctuations in the soil properties as the years go by, which could be attributed to seasonal changes.

Melkamu and Zerihun [16] highlighted that changes in atmospheric temperature alter the amount of rainfall within a geographical location.

From **Fig. 9–10**, the surge in discharge was higher within the first two years (2013), which decreased over the next ten years (2023). Subsequent increases are expected in the coming years. The fluctuation can be attributed to changes in temperature and rainfall levels during the subsequent years.

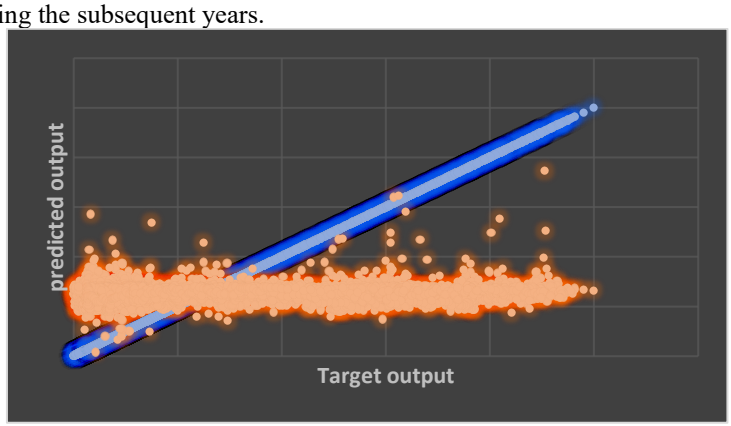


Fig. 9. SWAT prediction pattern of soil properties (2013)

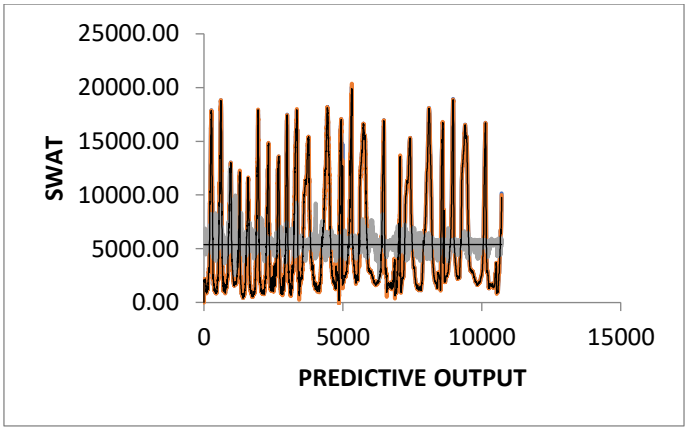


Fig. 10. SWAT prediction pattern of soil properties, (2023).

CONCLUSIONS

Excessive discharge, especially during the rainy season, has significant effects on the lives and properties of those within the affected areas. Predictive discharge values are important because they help in enacting laws.

This study provides real-time information on soil properties and their impact on water management, assisting policymakers in making informed decisions to mitigate the effects of climate change and land use for sustainable economic development.

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UTICAJ KORIŠĆENJA ZEMLJIŠTA I KLIMATSKIH PROMENA NA PARAMETRE ZEMLJIŠTA U NEKIM ODABRANIM LOKALNIM SAMOUPRAVAMA JUGOISTOČNE NIGERIJE, PRIMENOM SWAT MODELA

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Sažetak: Sve veći uticaji klimatskih promena i promena namene zemljišta pojavili su se kao veliki ekološki izazovi koji utiču na kvalitet vode u zemljištu, poljoprivrednu produktivnost i otpornost ekosistema, naročito u tropskim regionima.

Poslednjih decenija, porast globalnih temperatura, neredovne količine padavina i štetne ljudske aktivnosti poput krčenja šuma i intenzivne obrade zemljišta narušili su prirodnu hidrološku ravnotežu, što je dovelo do degradacije zemljišta, smanjenog obnavljanja podzemnih voda i opadanja kvaliteta vode.

Ova studija se fokusira na procenu uticaja klimatskih promena i promena namene zemljišta na sadržaj i kvalitet vode u zemljištu u odabranim lokalnim područjima jugoistočne Nigerije korišćenjem alata Soil and Water Assessment Tool (SWAT).

Model je korišćen za simulaciju hidroloških odgovora različitih scenarija namene zemljišta i klimatskih uslova na vlažnost zemljišta, površinsko oticanje i rečni proticaj u proučavanom području.

Studija je obuhvatila prikupljanje i integraciju prostornih podataka kao što su digitalni model reljefa (DEM), karte klasifikacije zemljišta, podaci o nameni zemljišta iz Landsat satelitskih snimaka, kao i klimatski podaci (padavine, temperatura, vlažnost vazduha i brzina vetra). Ovi skupovi podataka su obrađeni i uneti u SWAT model, koji je kalibrisan i validiran korišćenjem posmatranih hidroloških podataka za period od 2013. do 2023. godine. Kalibracija i analiza osetljivosti identifikovale su ključne parametre koji utiču na hidrološki odgovor, uključujući teksturu zemljišta, stopu infiltracije, evapotranspiraciju i intenzitet padavina.

Validacija modela dala je prihvatljive statističke rezultate, pokazujući zadovoljavajuću korelaciju između simuliranih i posmatranih vrednosti, čime je potvrđena pouzdanost simulacije za prediktivne analize. Izvedene su simulacije scenarija kako bi se ispitali uticaji različitih nivoa padavina i temperature, kao i različitih obrazaca namene zemljišta poput delimične i potpune deforestacije, širenja poljoprivrednih površina i pošumljavanja.

Rezultati analize pokazali su da povećana temperatura uz smanjene padavine značajno umanjuje vlažnost zemljišta, obnavljanje podzemnih voda i rečni proticaj. Nasuprot tome, pošumljavanje i pravilne prakse upravljanja zemljištem poboljšavaju zadržavanje vode u zemljištu, smanjuju eroziju i stabilizuju hidrološke cikluse.

Nalazi su pokazali sledeće apsolutne vrednosti i procentualne raspodele između 2013. i 2023. godine: gusta šuma 48128.76 (39.712%), poljoprivredno zemljište 35001.54 (28.881%), izgrađene/ogoljene površine 35237.07 (29.075%) i voda 2826.45 (2.332%). Za 2023. godinu: gusta šuma 29273.57 (24.237%), poljoprivredno zemljište 32031.00 (26.430%), izgrađene/ogoljene površine 57268.08 (47.253%) i voda 2521.17 (2.080%).

Ovo istraživanje pokazuje snažnu međuzavisnost između klimatske dinamike, obrazaca korišćenja zemljišta i sistema zemljište–voda. Studija naglašava neophodnost integrisanog upravljanja slivovima, klimatski pametne poljoprivrede i adaptivnog planiranja korišćenja zemljišta kao održivih strategija za ublažavanje negativnih posledica klimatskih promena.

Ključne reči: SWAT, digitalni model reljefa, hidrologija korišćenja zemljišta, ekosistemi

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THE SIGNIFICANCE OF THE FINANCIAL OPTIMAL PURCHASE OF AGRICULTURAL MECHANISM IN MEDIUM-SIZED AGRICULTURAL ENTERPRISES

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Abstract: The focus of the study was aimed at uncovering the impact of lending and joint investments within the framework of observing agricultural mechanization in the work of medium-sized agricultural enterprises in the Republic of Serbia.
We have established that there is a greater influence within the lending of agricultural mechanization in relation to joint investments of the same in the business of medium-sized agricultural enterprises in the Republic of Serbia.
Apart from that, the greatest impact, individually observed, is visible in the purchase of tractors in all years of observation (2023-2025) in relation to other forms of agricultural machinery analyzed in the regular business of medium-sized agricultural enterprises.
In addition, we have established that it is not possible to reliably predict the valuation of tractors based on other forms of valued agricultural machinery ($F=0.741$, $p<0.593$) in the work of medium-sized agricultural enterprises.

Key words*: Agricultural techniques, evaluation, form of procurement.*

INTRODUCTION

Achieving different influences on management decisions of top management in the sense of uncovering influences such as possible influence on crediting, crediting and then movements in connection with joint investments on the example of the overall evaluation of agricultural mechanization in agriculture is a very fundamental and strategic issue

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in the work of medium-sized agricultural companies in the Republic of Serbia, but also in a broader sense [1-7].

There are other major influences in making valid management decisions of the top management of medium-sized agricultural enterprises in the Republic of Serbia, and certainly the process of crediting agricultural machinery and management in relation to joint investments in agricultural machinery is one of the important influencing factors [8-15].

However, agricultural mechanization when viewed individually does not have the same importance for making important management decisions, as is the case with other individual parts of equipment evaluation [16-17].

Tractors, as a dominant category of agricultural machinery in the work of medium-sized enterprises, should be viewed from the point of view of financial valuation and not only as a technical matter of management decision-making by top management [18-21].

MATERIALS AND METHODS

The paper covers the observation period (2023-2025) in such a way that survey research was used. In this sense, 55 medium-sized companies were surveyed in the period from December 1-31 for the mentioned period 2023-2025, that is, the research covered a three-year period.

The research included the valuation of 155 randomly selected values of tractors, combines, i.e. procurement of new agricultural machinery.

And the research itself referred to the observation of lending for the purchase of all agricultural machinery in relation to joint investments in the mentioned equipment as two important financial procurement models.

In the paper, for the purpose of examining possible differences in the mentioned values of agricultural equipment, the application of one-factor analysis of variance (ANOVA) in Table 1-2 was used.

The second part of the research was based on predicting changes based on the evaluated tractors of all powers in relation to the mentioned forms of other analyzed agricultural parts of agricultural mechanization in the work of medium-sized agricultural enterprises in the Republic of Serbia, Table 3.

RESEARCH RESULTS AND DISCUSSIONS

The research investigated whether there is a significant difference in the value of the use of loans as well as joint investments of several agricultural enterprises in relation to the type of agricultural machinery as well as in relation to the procurement of the same by years of observation (2023-2025).

The obtained results of the research are grouped into two large parts in the presentation of Table 1-2, that is, in relation to the use of loans and joint investments in the purchase of new analyzed agricultural machinery.

Table 1. Use of loans in relation to the type of agriculture mechanization and procurement of the same

Business year	Tractors	Combine harvesters	Attached agricultural machines	Procurement of new agricultural machinery
2023	-0.071	-0.024	-0.029	-0.037
2024	0.081	0.080	-0.082	0.014
2025	-0.042	0.068	-0.049	0.025
Total	-0.022	0.040	-0.040	0.019

Based on the results of the correlation analysis, it can be seen that there is no significant connection between the purchase of new agricultural machinery and the use of loans in relation to the type of agricultural machinery (Table 1).

Table 2. Use of joint ventures in relation to the type of agriculture mechanization and its procurement

Business year	Tractors	Combine harvesters	Attached agricultural machines	Procurement of new agricultural machinery
2023	-0.050	0.078	0.010	0.013
2024	0.041	0.047	-0.049	0.032
2025	0.045	0.013	-0.017	0.069
Total	0.013	0.015	-0.016	0.013

Below, or in the second part of the research, the results of the presentation of correlations between the use of joint investments in relation to the acquisition of new agricultural machinery are given, viewed in relation to the type of agricultural machinery selected (Table 2).

The second part of the research presents the prediction of changes in valued tractors as the dominant category of influence within the observation of agricultural mechanization in the work of medium-sized agricultural enterprises, which is presented in Table 3.

Table 3. Prediction of changes in evaluated tractors of all powers in the work of medium-sized agricultural enterprises in the Republic of Serbia

	Beta	t	p
Constant	-	5.378	<0.0005*
Combine harvesters	-0.030	-0.396	0.690
Attached agricultural machines	-0.089	-0.110	0.911
Procurement of new agricultural machinery	0.025	0.341	0.729

Therefore, it can be seen that all independent variables do not have a significant impact on predicting changes in relation to the values of tractors operated by medium-sized agricultural enterprises, as shown in Table 3 of this research.

One-factor analysis of variance (ANOVA) was used to examine the differences in set and mentioned values.

First, based on the results of the ANOVA test shown in Table 1-2, it can be observed that significant differences are visible in relation to the observed forms of financing the purchase of agricultural machinery through lending or joint loans of several legal entities in relation to the procurement of new agricultural machinery.

Second, in addition, differences are visible for the entire period of observation by years of observation in relation to the analyzed types of agricultural machinery (2023-2025).

Thirdly, the existence of clearly expressed higher values for tractors compared to the analyzed combine harvesters and attached agricultural machinery is visible.

Fourthly, there is significantly more influence in the observation of all forms of agricultural mechanization in the form of procurement through credit compared to the form of procurement of agricultural mechanization through joint venture procurement.

Fifth, multiple regression analysis was applied to predict the change in relation to the valuation of tractors as the most important agricultural technique in the business of medium-sized enterprises in the agricultural production of the Republic of Serbia based on the value of combines, attachment machinery and procurement of new agricultural machinery.

The regression analysis yielded a coefficient of determination of 0.016, on the basis of which it can be concluded that the obtained model describes 1.6% of the total variance.

Changes in the value of tractors as the most important agricultural machinery cannot be predicted based on the value of combine harvesters, attachment machinery and the purchase of new agricultural machinery since the model obtained is not statistically significant ($F=0.741$, $p=0.593$).

Overall, the observed results are compatible with already published works that unify the issue of top management decision-making, evaluation and focus on the subject of leading technical support to management in relation to financing models as a source for procurement by agricultural medium-sized enterprises [22-27].

CONCLUSION

The study clearly shows that the following conclusions can be observed.

First, that the realistic observation of valued agricultural machinery is more influenced by the credit ratio in relation to joint investments in the procurement of agricultural machinery.

The second stated previous basic position is strengthened by the existence of differences for all years of observation (2023-2025) both in relation to the analyzed forms of agricultural mechanization in the regular operations of medium-sized agricultural enterprises and in relation to the two forms of procurement, i.e. in relation to lending and joint procurement.

The third largest influence on the business of medium-sized agricultural enterprises is the evaluated tractors within the analyzed agricultural mechanization.

The fourth prediction in evaluating tractors, as the most important agricultural machinery, cannot be reliably made through the assessment of combine harvesters, attachments, and new machinery purchases alone. Additional research is needed, such as analyzing different top management decisions and comparing tractors with other valuable company assets.

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ZNAČAJ FINANSIJSKE OPTIMALNE NABAVKE POLJOPRIVREDNE MEHANIZACIJE U SREDNJIM POLJOPRIVREDNIM PREDUZEĆIMA

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Abstrakt: Fokus studije bio je usmeren na otkirvanje uticaja kreditiranja i zajedničkih ulaganja u okviru posmatranja poljoprivredne mehanizacije u radu srednjih poljoprivrednih preduzeća u Republici Srbiji.
Ustanovljeno je da postoji veći uticaj u okviru kreditiranja poljoprivredne mehanizacije u odnosu na zajednička ulaganja u poljoprivrednu mehanizaciju u poslovanju srednjih poljoprivrednih preduzeća u Republici Srbiji.
Osim toga najveći uticaj pojedinačno posmatran vidljiv je u nabavci traktora u svim godinama posmatranja (2023-2025) u odnosu na ostale oblike poljoprivredne analizirane mehanizacije u redovnom poslovanju srednjih poljoprivrednih preduzeća.
Pored toga, ustanovljeno je da se ne može izvršiti sigurno predviđanje vrednovanja traktora na osnovu ostalih oblika vrednovane poljoprivredne mehanizacije ($F=0.741$, $p<0.593$) u radu srednjih poljoprivrednih preduzeća.

Ključne reči: *Poljoprivredna tehnika, vrednovanje, oblik nabavke.*

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CREDIT FOR AGRICULTURAL MACHINERY WITH OR WITH OUT IT SUPPORT IN THE PREPARATION OF DOCUMENTATION FOR MEDIUM-SIZED AGRICULTURAL ENTERPRISES

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Abstract: Lending is one of the important ways of buying agricultural machinery - It is of particular importance for the business of medium-sized agricultural companies that need to take into account the complex perception of numerous influencing factors, above all the influence on the formation of the level of interest rates as the driver of all purchases, especially equipment. It was found that there is a significant difference if the documentation that was made for the purposes of obtaining a loan was previously controlled by IT support systems in comparison to documentation where there was no control through IT. Apart from that, the biggest influence of individual factors on crediting is given by the following factors: management of loans, i.e. credit flow, participation in loans and interest rates within the overall overview of purchases of agricultural machinery in the regular business of medium-sized agricultural enterprises. All of this was reinforced by the fact that it was discovered that it is possible to predict the interest rate through other analyzed factors, especially loan repayment and lending of agricultural machinery, i.e. equipment, because they have a significant impact on the analyzed interest rate factor ($p<0.0005$).

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The obtained values of the interest rate can essentially be predicted based on the independent variables since the model is statistically significant ($F=185.22$, $p<0.0005$) and thus the overall process of lending agricultural machinery in the functioning of medium-sized agricultural enterprises can be observed.

***Key words**: lending, agricultural technology, business decision-making.*

INTRODUCTION

Numerous management factors in the work of medium-sized agricultural enterprises and other legal entities affect the real business, but basically the acquisition of agricultural and other equipment is one of the expensive factors that are essentially procured through loans, and it is the focus of numerous researches [1-6].

One of the extremely important issues in dealing with agricultural equipment and its procurement is the level of the interest rate, the prediction of which can essentially be predicted based on the analysis of numerous factors that, within the credit relationship, represent the analysis of independent variables that influence the making of management decisions by the decision-maker [7-11].

Monitoring equipment lending, i.e. the participation of loan beneficiaries, equipment lending, the minimum loan amount has an increasingly important significant influence on interest rates, which must be considered as an important starting point in the management of medium-sized agricultural enterprises within the framework of credit policy in Serbia [12-17].

In addition, the role and great importance of the application of IT within the overall credit policy regarding the procurement of agricultural machinery, which confirms the existence of essential differences, essentially refers to the modern management of one of the most important forms of organization in agriculture [18-22].

MATERIALS AND METHODS

Statistical data processing and analysis were done using the software IBM SPSS (Statistical Package of Social Science) version 25.

The survey included 118 documents with the use of IT assistance and 128 documents without the use of IT in a process that comprehensively covers the processes of crediting agricultural machinery in medium-sized agricultural enterprises in the Republic of Serbia.

The evaluation was carried out by top managers in the interval 1-10, with the least confidence being 1, and the highest rating being 10. The research period was December 1-30, 2025.

In the paper, the t-test of independent samples was applied to examine the difference between medium-sized agricultural enterprises that use IT and those that do not in the process of lending agricultural machinery from the point of view of the security of business decision-making.

Factors were analyzed: interest rates, credit-flow management, repayment, participation in loans, agricultural lending, adjustments to repayment of machinery, in total.

A regression analysis was performed, which was applied to predict the interest rate, based on the factors of loan management-flow, repayment and participation in loans, agricultural lending and adjustments to repayment of machinery.

At the same time, the threshold value of significance was at the level of 0.05.

RESEARCH RESULTS AND DISCUSSIONS

The business of purchasing agricultural machinery is mostly carried out with the existence of a credit relationship in the work of especially medium-sized agricultural companies.

The modern approach implies the application of IT technological support, which was the basis for obtaining the presentation of the research results that are present in the presentation of Table 1.

Table 1. Policy management of crediting agricultural machinery in medium-sized agricultural enterprises with and without the help of IT for 2025.

	With the use of IT support	Without IT help		
	Average value		t	p
Interest rates	9.01 ± 0.55	6.40 ± 0.48	36.369	<0.0005*
Credit flow management	9.59 ± 0.48	7.24 ± 1.15	17.041	<0.0005*
Repayment	7.58 ± 0.47	6.20 ± 4.07	4.211	<0.0005*
Participation in loans	9.45 ± 0.50	8.65 ± 0.85	8.194	<0.0005*
Lending of agricultural machinery	9.01 ± 0.62	4.75 ± 0.71	48.103	<0.0005*
Repayment adjustments	7.56 ± 0.70	9.79 ± 0.42	24.358	<0.0005*
Total score	63.21 ± 4.97	64.01 ± 2.65	-1.269	0.122

Based on the results shown in Table 1, the performance of medium-sized agricultural enterprises can be seen in relation to the results obtained with or without the application of IT in the process of overall consideration of the importance of individual organizational factors.

After displaying the results in Table 1, it can be seen that there are differences in lending conditions with or without IT assistance for 2025. In the following, a multiple linear regression was applied to examine whether, based on the analyzed factors, we can predict the influence of the interest rate factor in the process of crediting agricultural machinery by purchasing it from a loan Table 2.

Table 2. Prediction of the interest rate in relation to the analyzed factors of agricultural machinery lending

	Beta	t	p
Constant	-	11.903	<0.0005*
Credit flow management	-0.026	-1.070	0.279
Repayment	0.165	4.396	<0.0005*
Participation in loans	0.067	1.805	0.069
Lending of agricultural machinery	0.275	6.201	<0.0005*
Repayment adjustments	0.105	2.629	0.009*

The level of the interest rate can be predicted based on the independent variables since the model is statistically significant ($F=185.22$, $p<0.0005$).

Based on the results shown in Table 2, it can be seen that loan repayment, lending of agricultural machinery, i.e. equipment, have a significant impact on the analyzed factor, i.e. the interest rate factor that occurs in the operation of medium-sized agricultural enterprises within the framework of credit policy in Serbia.

The results shown in Table 1 clearly indicate that there is a great importance of the application of IT within the overall credit policy regarding the purchase of agricultural machinery, which confirms the existence of significant differences $p<0.0005$ for all analyzed factors.

All of this is reinforced based on the presentation of Table 2, i.e. predicting the interest rate based on the other analyzed factors is possible, i.e. it can be seen that there is a significant influence on the analyzed interest rate factor.

CONCLUSION

Realistic observation of valued agricultural machinery is more influenced by the credit ratio in relation to joint investments in the procurement of agricultural machinery.

After reviewing the study and the results reached by its authors, the existence of the following important points regarding the crediting of agricultural technology in the work of medium-sized agricultural enterprises is clearly seen.

First, there are significant differences in the first stage of crediting, that is, in the preparation of documentation, because the top management has more confidence in the fact that the documentation was prepared with the help or with the use of IT, as opposed to the one that was prepared without such support for all analyzed factors.

Other factors such as the participation of loan beneficiaries, equipment lending and the minimum loan amount have a significant impact on the analyzed factor (that is, the same can be predicted) of the interest rate that occurs in the operation of medium-sized agricultural enterprises within the framework of the credit policy in Serbia.

The essential factor of the interest rate can be predicted on the basis of independent variables since the model is statistically significant ($F=185.22$, $p<0.0005$) which shows as an important conclusion the essence of the study, which, apart from the theoretical approach, has practical managerial significance, especially since the results refer to the work of medium-sized agricultural enterprises in Serbia.

CONFLICT OF INTEREST

None is declared

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KREDITIRANJE POLJOPRIVREDNE MEHANIZACIJE SA ILI BEZ PODRŠKE IT U PRIPREMI DOKUMENTACIJE ZA POSLOVANJE U SREDNJIM POLJOPRIVREDNIM PREDUZEĆIMA

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Abstrakt: Kreditiranje je jedan od bitnih načina kupovine poljoprivredne mehanizacije. To je od naročite važnosti za poslovanje srednjih poljoprivrednih preduzeća koja treba da uvaže kompleksno posmatanje brojnih faktora uticaja, pre svega uticaja na formiranje visine kamatnih stopa kao pokretača svih nabavki, pre svega opreme.

Ustanovljeno je da postoji bitna razlika ukoliko se dokumentacija koja je urađena za potrebe dobijanja kredita prethodno kontrolisana IT sistemima podrške u odnosu na dokumentaciju gde nije postojala kontrola putem IT.
Osim toga najveći uticaj pojedinačnih faktora na kreditiranje imaju faktori: vođenje kredita odnosno kreditnog toka, učešća u kreditima i kamatne stope u okviru ukupnog sagledavanja nabavki poljoprivredne mehanizacije u redovnom poslovanju srednjih poljoprivrednih preduzeća.
Sve to je osnaženo na način da se utvrdilo da je moguće izvršiti predviđanje kamatne stope putem ostalih analiziranih faktora a naročito otplata kredita i kreditiranje poljoprivredne mehanizacije odnosno opreme, jer isti imaju značajan uticaj na analizirani faktor kamatne stope ($p<0.0005$).
Dobijene su vrednosti visine kamatne stope suštinski se može predvidi na osnovu nezavisnih varijabli pošto je model statistički značajan ($F=185.22$, $p<0.0005$) te se na taj način može posmatrati ukupnog procesa kreditranja poljoprivredne mehanizacije u funkcionisanju srednjih poljoprivrednih preduzeća.

Ključne reči: *Kreditiranje, poljoprivredna tehnika, poslovno odlučivanje.*

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REFERENCE EVAPOTRANSPIRATION ESTIMATION IN BENIN-OWENA RIVER BASIN USING DEEP LEARNING APPROACHES: A REVIEW

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Abstract: Reference evapotranspiration (ETo) is essential for water resource management. Yet, its accurate estimation in the Benin-Owena River Basin Development Authority (BORBDA) is constrained by sparse meteorological networks and incomplete data records. While the FAO Penman-Monteith method remains the standard, its application is limited by data scarcity. This literature review synthesizes existing research on ETo estimation within the BORB and examines the emerging potential of deep learning (DL) approaches. Conventional studies in the basin have primarily relied on empirical and basic machine learning models, revealing systematic data gaps and limited spatial coverage. In contrast, recent DL applications in similar humid tropical regions—such as the Amazon and Southeast Asia-have demonstrated superior performance, with architectures like Long Short-Term Memory (LSTM) and hybrid models effectively capturing complex temporal dependencies and achieving high accuracy even with limited inputs. Despite this success, a significant research gap remains: no comprehensive study has applied advanced DL techniques to ETo modelling in the BORB. This review highlights the critical opportunity to develop robust, DL-based tools tailored to the basin's unique climatic and data conditions. Advancing such methodologies could significantly enhance irrigation scheduling, agricultural water management, and climate adaptation strategies across one of Nigeria's most vital agricultural regions.

Keywords: *Reference evapotranspiration (ETo), Deep learning, Benin-Owena River Basin, Hydrological modeling, Data scarcity.*

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INTRODUCTION

Reference evapotranspiration (ETo) is a critical hydrological parameter for water resources planning, irrigation scheduling, and agricultural water management. Accurate estimation of ETo is particularly vital in river basins like the Benin-Owena River Basin Development Authority (BORBDA) in Nigeria, where rain-fed agriculture dominates and water scarcity increasingly threatens food security.

The Benin-Owena River Basin, covering approximately 33,700 km² across Edo, Delta, Ondo, and Ekiti States, experiences a humid tropical climate with distinct wet and dry seasons, making accurate ETo estimation essential for sustainable water resource management.

Traditional ETo estimation methods, particularly the Food and Agriculture Organization (FAO) Penman-Monteith (PM) equation, require extensive meteorological data, including temperature, humidity, wind speed, and solar radiation. However, many stations within the BORB suffer from incomplete data records, necessitating alternative estimation approaches.

In recent years, deep learning (DL) techniques have emerged as powerful tools for ETo modeling, capable of capturing complex nonlinear relationships between meteorological variables and evapotranspiration without requiring full parametric specifications.

This literature review synthesizes existing research on ETo estimation within the Benin-Owena River Basin context and examines the application of deep learning approaches for evapotranspiration modeling, identifying research gaps and opportunities for advancing hydrological prediction in the region.

OVERVIEW OF THE BENIN-OWENA RIVER BASIN

Geographic and Climatic Characteristics

The Benin-Owena River Basin is situated in southwestern Nigeria, bounded approximately by latitudes 5°50′N to 7°30′N and longitudes 4°30′E to 6°00′E. The basin encompasses major river systems including the Benin River, Owena River, and their tributaries, draining into the Atlantic Ocean.

Topography ranges from coastal lowlands in the south to undulating hills in the north, with elevations varying from sea level to approximately 600 meters.

The climatic regime is characterized by a tropical monsoon pattern with mean annual rainfall ranging from 1,500 mm in the northern sections to over 2,500 mm along the coastal areas. The region experiences two distinct seasons: a wet season spanning April to October and a dry season from November to March. Mean annual temperatures range from 25°C to 28°C, with relative humidity typically exceeding 80% during the wet season [1].

Agricultural and Water Resources Significance

The Benin-Owena River Basin supports diverse agricultural activities including oil palm cultivation, rubber production, rice farming, and mixed cropping systems. The basin is also home to several major dams, including the Owena Dam (Ondo State) and the Ikpoba Dam (Edo State), which provide water for irrigation, domestic supply, and industrial uses. Accurate ETo estimation is essential for optimizing irrigation schedules, particularly during the dry season when water demand peaks and supplies become constrained.

Despite its agricultural significance, the basin faces challenges, including limited meteorological stations, data gaps, and inadequate water management infrastructure.

The Nigerian Hydrological Services Agency (NIHSA) operates limited stations within the basin, and many existing stations suffer from instrumentation failures and data discontinuity, creating significant challenges for conventional ETo estimation methods [2].

REFERENCE EVAPOTRANSPIRATION: CONCEPTS AND ESTIMATION METHODS

Definition and Importance

Reference evapotranspiration (ETo) represents the evapotranspiration rate from a hypothetical grass reference surface with specific characteristics: a height of 0.12 m, surface resistance of 70 s m^{-1}, and albedo of 0.23 [3]. ETo serves as a baseline for estimating crop water requirements when combined with crop coefficients (*Kc*). Accurate ETo estimation directly influences irrigation scheduling, water allocation, and agricultural productivity.

Conventional Estimation Methods

Several empirical and physically based methods exist for ETo estimation, ranging from simple temperature-based approaches to complex combination equations:

Temperature-Based Methods: The Hargreaves-Samani equation, requiring only temperature data, remains widely used in data-scarce regions. However, its accuracy varies significantly across climatic conditions and often underestimates ETo in humid tropical environments [4].

Radiation-Based Methods: The Priestley-Taylor and Turc methods utilize solar radiation and temperature data. While simpler than combination methods, they perform variably under different humidity regimes [5].

Combination Methods: The FAO-56 Penman-Monteith equation is the standard method for ETo estimation, combining energy-balance and aerodynamic components. It requires data on temperature, humidity, wind speed, and solar radiation, providing reliable estimates across diverse climatic conditions [3].

Limitations in Data-Scarce Environments

Within the Benin-Owena River Basin, meteorological stations are sparse and unevenly distributed.

The Nigerian Meteorological Agency (NIMET) operates limited synoptic stations in Benin City, Akure, and Warri, while many agricultural stations lack complete instrumentation. This data scarcity poses significant challenges for implementing the FAO-56 Penman-Monteith method, necessitating alternative approaches that can operate with limited inputs [6].

DEEP LEARNING APPROACHES FOR EVAPOTRANSPIRATION ESTIMATION

Overview of Deep Learning in Hydrology

Deep learning, a subset of machine learning employing artificial neural networks with multiple hidden layers, has demonstrated remarkable capabilities in hydrological modeling.

Unlike traditional statistical methods, deep learning models can automatically extract relevant features from input data, capture complex temporal dependencies, and model nonlinear relationships without requiring explicit physical parameterization [7].

In evapotranspiration modeling, deep learning approaches have shown superior performance compared to conventional empirical equations, particularly in data-limited settings where complete meteorological observations are unavailable [8].

Deep Learning Architectures for ETo Estimation

Artificial Neural Networks (ANNs): The earliest deep learning applications for ETo utilized feedforward ANNs with multiple hidden layers. These models have demonstrated effectiveness in estimating ETo from limited meteorological inputs, often achieving lower error metrics than empirical equations. [9] reported that ANNs outperformed Hargreaves-Samani and Blaney-Criddle methods across multiple climatic zones in Iran.

Recurrent Neural Networks (RNNs): RNNs, particularly Long Short-Term Memory (LSTM) networks, are specifically designed to handle sequential data and capture temporal dependencies. Given the inherent temporal structure of meteorological processes, LSTMs have shown particular promise for ETo modeling. For example, [10] demonstrated that LSTM models achieved higher accuracy than ANNs for daily ETo estimation in the Yellow River Basin, China.

Convolutional Neural Networks (CNNs): While primarily developed for image processing, CNNs have been adapted for time-series analysis in hydrology. Their ability to extract local patterns from sequential data makes them suitable for capturing periodic meteorological patterns. [11] successfully applied hybrid CNN–LSTM architectures for ETo estimation in Brazilian watersheds.

Hybrid and Ensemble Approaches: Recent research has explored hybrid architectures combining multiple deep learning techniques with wavelet transforms, genetic algorithms, or physical constraints. These approaches aim to leverage the strengths of different methods while compensating for individual limitations. [12] reported that wavelet-coupled ANNs improved ETo estimation accuracy compared to standalone models in Mediterranean climates.

Performance Comparison with Conventional Methods

Extensive comparative studies have evaluated deep learning (DL) performance against conventional ETo estimation methods (Table 1):

Table 1. Performance of deep learning methods compared to FAO-56 PM

Study	Location	DL Method	Performance vs FAO-56 PM
Ferreira et al., [71]	Brazil	LSTM	RMSE reduced by 25–40%
Wang et al., [10]	China	LSTM	R^2 = 0.92–0.96 with limited inputs
Gocić et al., [12]	Serbia	Wavelet-ANN	$R^2 \approx 0.94$, outperformed Hargreaves
Majhi et al., [13]	India	CNN–LSTM	MAE reduced by 35% vs empirical methods

EXISTING ETO STUDIES IN THE BENIN-OWENA RIVER BASIN

Conventional Estimation Studies

Several studies have evaluated ETo estimation methods within the Benin-Owena River Basin:

[14] compared the FAO-56 PM, Hargreaves-Samani, and Blaney-Criddle methods at stations in Benin City and Akure. Their results indicated that FAO-56 PM provided the most consistent estimates, while Hargreaves-Samani exhibited systematic underestimation during the wet season. The study recommended calibration of temperature-based methods for local conditions.

[15] assessed seasonal variability of ETo across the BORB using 20-year meteorological records from NIMET stations. Their analysis revealed distinct spatial patterns, with higher ETo values in the northern basin (up to 4.5 mm day^{-1} during the dry season) and lower values near the coast (3.2–3.8 mm day^{-1}). The study noted significant data gaps that limited a comprehensive basin-wide assessment.

[16] developed regional calibration coefficients for the Hargreaves-Samani equation using data from six stations across Edo and Ondo States. Their calibrated model achieved an R^2 of 0.81 compared to FAO-56 PM, a significant improvement over the uncalibrated version (R^2 = 0.64). However, validation at independent stations showed reduced performance, highlighting the need for robust methods that generalize across the basin.

Machine Learning Applications

Recent studies have explored the use of machine learning (ML) techniques for ETo estimation within and beyond the Benin-Owena River Basin, particularly in response to data limitations associated with conventional methods.

[17] Applied Support Vector Machines (SVM) and Random Forest (RF) models for ETo estimation using limited climatic variables from stations in southern Nigeria.

Their findings indicated that RF outperformed SVM and traditional empirical methods, achieving higher accuracy and better generalization across seasons.

[18] investigated the performance of Artificial Neural Networks (ANNs) for ETo prediction in Ondo State using temperature and relative humidity data. The ANN model demonstrated strong predictive capability, with results closely matching FAO-56 PM estimates despite reduced input requirements.

Furthermore,[19] compared multiple machine learning algorithms, including Gradient Boosting and Extreme Learning Machines (ELM), for ETo estimation across southwestern Nigeria. Their results showed that ensemble-based models provided improved accuracy and robustness, particularly under conditions of missing or incomplete meteorological data.

Despite these advancements, the application of advanced deep learning architectures such as LSTM and CNN within the Benin-Owena River Basin remains limited. Most existing studies rely on relatively simple ML models and short-term datasets, highlighting a significant research gap in the adoption of more sophisticated techniques capable of capturing temporal dynamics and spatial variability.

1. Absence of deep learning applications: No published study has applied advanced deep learning (DL) architectures (LSTM, CNN, hybrid models) for ETo estimation within the Benin-Owena River Basin.

2. Limited basin-wide assessments: Existing studies typically focus on individual stations or small clusters, lacking a comprehensive basin-wide evaluation.

3. Inadequate temporal analysis: The temporal structure of ETo patterns, including seasonal and interannual variability, remains underexplored.

4. Uncertainty quantification: Limited attention has been paid to quantifying prediction uncertainty in ETo estimates.

5. Integration with water management: Few studies have linked ETo estimation with practical water management applications within the basin.

COMPARATIVE ANALYSIS: DEEP LEARNING STUDIES IN SIMILAR CLIMATIC REGIONS

To contextualize potential DL applications in the BORB, it is valuable to examine studies from regions with similar tropical humid climates:

West Africa Region: [20] applied LSTM networks for ETo estimation across Senegal using satellite-derived meteorological inputs. Their model achieved R^2 values exceeding 0.90 across multiple stations, demonstrating the feasibility of DL approaches in West African contexts. The study highlighted the importance of proper model architecture selection for regional applications.

Southeast Asia: [21] evaluated multiple deep learning (DL) architectures for ETo estimation in Vietnam's Mekong Delta, a region with similar humid tropical characteristics to the BORB. Their results showed that LSTM models significantly outperformed ANNs and empirical equations, with the greatest improvements observed during periods of limited data availability.

Amazon Basin: [22] conducted a comprehensive benchmarking of DL methods for ETo across Brazilian Amazon stations. They found that ensemble approaches combining multiple DL architectures produced the most robust estimates, with prediction intervals effectively capturing uncertainty.

Table 2. Key Lessons for Benin-Owena Applications

Factor	Lesson	Implication for BORBDA
Data scarcity	LSTM effective with limited inputs	Suitable for sparse station network
Tropical variability	Models capture seasonal patterns	Applicable to BORB bimodal rainfall
Transfer learning	Pre-trained models reduce data needs	Potential for regional generalization
Uncertainty	Quantification improves decision-making	Critical for irrigation management

METHODOLOGICAL FRAMEWORK FOR DEEP LEARNING ETO MODELING

Data Requirements and Sources

For successful DL implementation in the BORB, the following data sources are available (Table 3):

Table 3. Data Sources and Availability

Data Type	Source	Availability
Temperature	NIMET, NIHSA	Daily records, 1970–present
Humidity	NIMET	Daily records, gaps present
Wind speed	NIMET	Limited stations
Solar radiation	NIMET (computed)	Derived from sunshine hours
Evaporation	NIHSA	Pan evaporation data

Model Development Considerations

Input Selection: Optimal input combinations for DL models in tropical environments typically include daily maximum and minimum temperature, relative humidity, wind speed, and extraterrestrial radiation. Studies suggest that models using 3–5 input variables achieve performance approaching full-input models in humid tropical settings [8].

Temporal Resolution: Daily ETo estimation requires consideration of temporal dependencies. LSTM models typically utilize input sequences of 7–30 days to capture antecedent conditions and seasonal patterns.

Validation Strategies: Given the limited station network, cross-validation across stations and temporal hold-out periods is essential for assessing model generalization. K-fold validation with spatial separation ensures robust performance evaluation.

Proposed Architectural Approaches

Based on successful applications in analogous regions, the following architectures are recommended for BORB applications:

1. LSTM networks: For capturing temporal dependencies in meteorological sequences
2. Hybrid CNN-LSTM: For extracting local patterns while maintaining temporal memory
3. Attention-based models: For identifying critical time steps influencing ETo
4. Ensemble methods: For improving robustness and uncertainty quantification

CHALLENGES AND FUTURE DIRECTIONS

Data Challenges

- Sparse observations: Limited meteorological stations constrain model training and validation.
- Data quality issues: Instrument failures, inconsistent recording, and missing values require robust preprocessing.
- Temporal inconsistency: Changing instrumentation and measurement protocols create inhomogeneities.

Future Research Directions

1. Satellite data integration: Incorporating remote sensing products (e.g., MODIS, Landsat) for spatial coverage.
2. Climate change applications: Assessing ETo trends under changing climatic conditions.
3. Real-time forecasting: Developing operational systems for irrigation scheduling.
4. Hybrid physics-DL models: Incorporating physical constraints to improve accuracy and generalizability.
5. Regional model development: Creating basin-specific models that generalize across the BORB.

CONCLUSIONS

Reference evapotranspiration estimation remains a critical challenge for water resources management in the Benin-Owena River Basin. Conventional methods, while established, face limitations due to data scarcity and the complex climatic characteristics of the region. Deep learning approaches offer promising alternatives, with demonstrated success in similar tropical environments across West Africa, Southeast Asia, and South America.

The existing literature reveals a significant research gap: no comprehensive deep learning-based ETo modelling has been conducted for the Benin-Owena River Basin. This gap presents an opportunity to develop advanced estimation tools that can improve water management, enhance agricultural productivity, and contribute to climate adaptation efforts in one of Nigeria's most important agricultural regions.

Future research should focus on developing and validating LSTM-based and hybrid deep learning architectures specifically tailored to the BORB's climatic and data characteristics, integrating available meteorological records, satellite products, and domain knowledge to produce robust, operational ETo estimation tools.

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PROCENA REFERENTNE EVAPOTRANSPIRACIJE U BASENU REKE BENIN-OVENA KORIŠĆENJEM PRISTUPA DUBOKOG UČENJA: - PREGLED

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Apstrakt: Referentna evapotranspiracija (ETo) je neophodna za upravljanje vodnim resursima. Međutim, njena tačna procena u Upravi za razvoj sliva reke Benin-Ovena (BORBDA) je ograničena oskudnim meteorološkim mrežama i nepotpunim zapisima podataka.

Iako Penman-Montejt metoda FAO ostaje standard, njena primena je ograničena nedostatkom podataka.

Ovaj pregled literature sintetiše postojeća istraživanja o proceni ETo unutar BORBDA (Benin-Owena River Basin Development Authority) i ispituje novi potencijal pristupa dubokog učenja DL (Deep Learning).

Konvencionalne studije o slivu reke su se prvenstveno oslanjale na empirijske i osnovne modele mašinskog učenja, otkrivajući sistematske nedostatke u prikupljenim podacima i ograničenu prostornu pokrivenost.

Nasuprot tome, nedavne primene dubokog učenja (DL) u procesu evapotranspiracije u sličnim vlažnim tropskim regionima – kao što su Amazon i Jugoistočna Azija – pokazale su superiorne performanse, sa arhitekturama poput dugoročno-kratkoročno memorije Long Short-Term Memory (LSTM) i hibridnim modelima koji efikasno obuhvataju složene vremenske zavisnosti i postižu visoku tačnost, čak i sa ograničenim ulaznim podacima.

Uprkos ovom uspehu, ostaje značajan istraživačka prepreka: nijedna sveobuhvatna studija nije primenila napredne tehnike DL (Deep Learning) na ETo modeliranje u slivu BORB (Benin-Owena River Basin).

Ovaj pregled ističe kritiku prilike za razvoj robusnih, DL (Deep Learning) baziranih alata, prilagođenih jedinstvenim klimatskim i podacima uslovima basena reke Benin-Ovena. Unapređenje takvih metodologija moglo bi značajno poboljšati postavljanje i kontrolu navodnjavanja, upravljanje poljoprivrednim vodama i strategije prilagođavanja klimatskim promenama u jednom od najvitalnijih poljoprivrednih regiona Nigerije.

Ključne reči: *Referentna evapotranspiracija (ETo), duboko učenje, basen reke Benin-Ovena, hidrološko modeliranje, nedostatak podataka.*

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MANAGING MEDIUM SIZED AGRICULTURAL ENTERPRISES AND MACHINERY PROCUREMENT: -THE IMPACT OF COMPREHENSIVE VS PARTIAL IT SYSTEM SUPPORT

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Abstract: Procurement of agricultural machinery is one of the economically important factors in the business of a large number of legal entities in agriculture. This is of particular importance for the business of medium-sized agricultural companies that are looking for ways to improve procurement. It was established that there is a significant difference if the procurement of agricultural machinery is carried out with the full support of the IT system in relation to the way of doing business of medium-sized agricultural enterprises where the procurement is carried out with a partial determination of the procurement procedure of agricultural machinery. This is reinforced by the presentation of the results in Table 1, where for all forms of procurement, i.e. for: large investment parts for the maintenance of agricultural machinery, for the procurement of agricultural tools, parts for the maintenance of attachment machines, parts of procurement for the maintenance of trailers, i.e. for their total score, higher values appear, which indicates greater trust of the decision-maker if the procurement was made with the systemic support of the IT system compared to the business, i.e. the procurement where there is partial support from the IT support system.
All of this is strengthened after the presentation in Table 2, that is, the forecast of the procurement, where the value of the procurement of large investment parts for the maintenance of agricultural machinery was taken as the basis, using the system support of the procurement through the IT system.

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The obtained results are in favor of IT system support during the procurement of parts for the maintenance of agricultural machinery in relation to partial support for all analyzed forms as well as their score, because the values are significant ($p<0.0005$) in the functioning of the procurement of parts for agricultural machinery in the business of medium-sized agricultural enterprises.

***Key words**: procurement, IT, agricultural machinery, maintenance.*

INTRODUCTION

The operations of medium-sized and other agricultural enterprises depend on the realistic application of numerous management factors, where the factor of purchasing agricultural equipment is often the focus of interest due to costs [1-5].

The procurement of agricultural equipment should take into account the assistance of a number of heterogeneous factors, especially IT support system factors, which can positively influence the making of valid management decisions [6-11].

The procurement of agricultural equipment as part of the overall process in managing medium-sized agricultural enterprises in Serbia is a current issue due to the overall consideration of business costs [12-17].

The issue of practical and valid application of IT within the overall procurement of agricultural mechanization is increasingly being given great importance to procurement processes, which refers to the modern management of one of the most important forms of organization in agriculture, i.e. in the operations of medium-sized agricultural enterprises [18-20].

MATERIALS AND METHODS

Statistical data processing and analysis were done using the software IBM SPSS (Statistical Package of Social Science) version 25. The t-test of independent samples was applied in the paper to examine the difference between the systematic procurement of agricultural parts using the IT support system in connection with the maintenance of agricultural machinery and the partial support of procurement of the aforementioned parts of the maintenance of agricultural machinery.

The following were analyzed: major investment parts of maintenance of agricultural machinery, agricultural tools, maintenance parts of attached machines, maintenance parts of trailers, i.e. their total score.

The survey included a survey of 226 medium-sized enterprises that were completed by the owners or top management of the mentioned enterprises, in such a way that the system procurement with the application of IT included 143 entities, as well as with the partial application of the IT system in the procurement of parts by 83 entities included in the survey.

The survey gave the opportunity to evaluate trust in the form of procurement in an interval of 1-10, with the highest trust being possible to rate with 10 and the weakest with 1.

In the second part of the research, a multiple regression analysis was used to predict the purchase of large investment parts for the maintenance of agricultural machinery.

A level of 0.05 was used for the threshold value of significance.

RESEARCH RESULTS AND DISCUSSIONS

The research provides an overview of the differences in the two models of procurement of agricultural machinery in the work of medium-sized enterprises operating in the Republic of Serbia in January 2026.

The t test of independent samples was used to examine the differences.

The obtained results are shown in Table 1.

Table 1. Differences in relation to the partial and majority application of the IT support system in the procurement of agricultural parts for the maintenance of agricultural machinery

	System implementation of the IT procurement support system (N=145)	Partial implementation of the IT procurement support system (N=82)	t	p
	Average value			
Large investment parts of maintenance of agricultural machinery	7.67 ± 0.41	3.88 ± 0.44	61.768	<0.0005*
Agricultural tools	7.59 ± 0.38	6.88 ± 0.45	13.598	<0.0005*
Maintenance parts for	9.01 ± 0.40	6.21 ± 0.41	45.499	<0.0005*
railer maintenance parts	8.38 ± 0.30	7.09 ± 0.87	15.756	<0.0005*
Total	6.97 ± 0.26	6.37 ± 0.85	8.491	<0.0005*

Based on the results of the t-test shown in Table 1 it can be observed that for all types of procurement of parts of agricultural machinery as well as the total score, there is a statistically significant difference, where the value in terms of security of procurement in favor of IT system support as a support system in the procurement of parts of agricultural machinery is higher compared to the same when there is partial support for procurement by the IT system at the beginning of 2026 in the Republic of Serbia.

The second part of the research was the application of multiple linear regressions with the aim of seeing the impact of the possible forecasting of the large-scale purchase of agricultural machinery through a systematic procurement approach.

The systematized results are presented in Table 2.

Table 2. Forecasting the procurement of large investment parts for the maintenance of agricultural machinery and the system application of IT systems

	Beta	t	p
Constant	-	19.921	<0.0005*
Agricultural tools	-0.751	-17.101	<0.0005*
Excessive supply of agricultural products	-0.321	-9.472	<0.0005*
Maintenance parts for attachment machines	-0.021	-0.289	0.713
Trailer maintenance parts	0.016	0.342	0.604

The regression analysis yielded a coefficient of determination of 0.32, on the basis of which it can be concluded that the obtained model describes 32% of the total variance.

This shows that predicting the procurement of large investment parts for the maintenance of agricultural machinery with the system support of the IT procurement system is statistically significant as a model ($F=68.002$, $p<0.0005$).

Based on the results shown in Table 2, it can be seen that the systematic application of the IT procurement support system for all analyzed forms of procurement of agricultural machinery is a much safer procurement system, which is such that the owner and top management have much more confidence compared to the model of partial application of IT in the procurement of the mentioned forms of procurement of agricultural machinery.

CONCLUSION

The practical functioning of medium-sized agricultural enterprises in the Republic of Serbia is extremely important when viewed through the procurement of means of maintenance of agricultural machinery. The obtained results indicate the following peculiarities within the overall overview of procurement of means for the maintenance of agricultural machinery.

First, the procurement of funds for the procurement of agricultural machinery is much safer ($p<0.0005$) based on the evaluation of the key holders in the business of medium-sized enterprises if it is carried out with systematic procurement support using the IT system compared to the procurement where it was carried out with partial support of the IT system.

Secondly, the systematic application of the IT procurement support system for all analyzed forms of procurement of agricultural machinery is a much safer procurement system in the opinion of the owners and top management because they have much more confidence in relation to the model of partial application of IT in the procurement of the mentioned forms of procurement of agricultural machinery.

Thirdly, it is possible to predict procurement based on large-scale investment parts for the maintenance of agricultural machinery with the systemic support of the IT procurement system because a model was obtained that is essentially statistically significant ($F=68.002$, $p<0.0005$) for all other analyzed forms of procurement of parts necessary for the operation of agricultural machinery that are used in the business of medium-sized agricultural enterprises.

CONFLICT OF INTEREST

None is declared

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UPRAVLJANJE SREDNJE VELIKIM POLJOPRIVREDNIM PREDUZEĆIMA I NABAVKOM MEHANIZACIJE: -UTICAJ SVEOBUHVATNE NASPRAM DELIMIČNE PODRŠKE IT SISTEMA

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Abstrakt: Nabavka poljoprivredne mehanizacije je jedan od ekonomsko bitnih faktora poslovanja velikog broja pravnih lica u agraru. To je od naročite važnosti za poslovanje srednjih poljoprivrednih preduzeća koja traže načine unapredjivanja nabavke. Ustanovljeno je da postoji bitna razlika ukoliko se nabavka poljoprivredne mehanizacje sprovede uz potpunu podršku IT sistema u odnosu na način poslovanja srednjih poljoprivrednih preduzeća gde se nabavka obavlja uz delimično utvrđenje procedure nabavki poljoprivredne mehanizacije. To je potvrđeno prikazom rezultata u Tabeli 1, gde se kod svih oblika nabavki odnosno za: krupne investicione delove održavanja poljoprivredne mehanizacije, za nabavku poljoprivrednih alata, delova održavanja priključnih mašina, delova nabavki za održavanje prikolica, odnosno za njihov ukupni skor javljaju vrednosti veće što ukazuje na veće poverenje nosioca odlučivanja ako je nabvka urađena uz sistemsku podršku IT sistema u odnosu na poslovanje odnosno nabavku kod koje postoji delimična podrška IT sistema podrške. Navedeno je potvrđeno nakon prikaza rezuleta u Tabeli 2, odnosno urađenog predviđanja nabavke gde je za osnovu uzeta vrednost nabavki krupnih investicionih delova za održavanje poljoprivredne mehanizacije primenom sistemske podrške nabavke putem IT sistema. Dobijeni rezultati su bili u korist sistemske podrške IT sistema primenjenog prilikom nabavki delova za održavanje poljoprivredne mehanizacije u odnosu na delimičnu podršku i to za sve analizirane oblike nabavki kao i njihovog skora, jer su dobijene vrednosti bile zanačajne ($p<0.0005$) u funkcionisanju nabavki delova za poljoprivrednu mehanizaciju, kod poslovanja srednjih poljoprivrednih preduzeća.

Ključne reči: *Nabavka, IT, poljoprivredna mehanizacija, održavanje.*

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A CRITICAL REVIEW OF PRINCIPAL COMPONENT ANALYSIS OF GROUNDWATER CONTAMINATION IN NIGERIA

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Abstract: Groundwater remains the most reliable source of potable water in Nigeria, particularly in rural and peri-urban areas. However, increasing anthropogenic activities —ranging from oil exploration and industrial effluents to agricultural practices and improper waste disposal—have intensified contamination pressures on this vital resource. Principal Component Analysis (PCA) has emerged as a powerful multivariate statistical tool for identifying pollution sources, understanding contaminant pathways, and interpreting complex hydrogeochemical datasets.

This review critically examines the application of PCA in groundwater contamination studies across Nigeria, synthesizing findings from peer-reviewed literature spanning the past two decades. The review evaluates methodological approaches, identifies common limitations, and assesses the effectiveness of PCA in source apportionment. Key findings reveal that while PCA has been widely applied in the Niger Delta region for petroleum hydrocarbon contamination studies, its application in other regions and for other contaminant classes (e.g., heavy metals, nitrates, pharmaceuticals) remains limited.

Common methodological shortcomings include inadequate data preprocessing, insufficient sample sizes, lack of validation, and over-interpretation of components. This review proposes standardized protocols for PCA application in Nigerian groundwater studies. It identifies priority areas for future research, including the integration of PCA with geospatial techniques and machine learning approaches. The findings underscore the need for rigorous statistical practices to enhance the reliability of source identification and support evidence-based groundwater management policies in Nigeria.

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Key words: *Principal Component Analysis, Groundwater Contamination, Nigeria, Source Apportionment, Multivariate Statistics, Hydrogeochemistry.*

INTRODUCTION

Groundwater constitutes approximately 22% of the world's freshwater resources and serves as the primary source of drinking water for over 50% of the global population [1]. In Nigeria, groundwater dependence is even more pronounced, with an estimated 70–80% of the population relying on groundwater for domestic, agricultural, and industrial purposes [2,3].

The country's extensive sedimentary basins, including the Chad Basin, Sokoto Basin, and the Niger Delta Basin, host significant groundwater resources that are increasingly threatened by contamination.

Groundwater contamination in Nigeria stems from diverse sources, reflecting the country's complex environmental landscape. In the oil-rich Niger Delta, petroleum hydrocarbon pollution from crude oil spills, pipeline leakages, and artisanal refining has been extensively documented [4,5]. In urban centers such as Lagos, Kano, and Port Harcourt, industrial effluents, municipal solid waste leachates, and inadequate sanitation infrastructure contribute to elevated concentrations of heavy metals, nitrates, and emerging contaminants [6,7]. Agricultural regions face challenges from fertilizer and pesticide runoff, while mining activities in states like Plateau and Nasarawa introduce heavy metals into groundwater systems [8].

The Role of Multivariate Statistics

Traditional approaches to groundwater quality assessment have relied heavily on univariate statistical methods and simple comparisons with regulatory standards. While these approaches provide basic information on contaminant levels, they fail to elucidate the complex relationships between multiple variables or identify the underlying sources of contamination. This limitation has driven the increasing adoption of multivariate statistical techniques, among which Principal Component Analysis (PCA) has emerged as the most widely applied.

PCA is a dimension-reduction technique that transforms a set of correlated variables into a smaller set of uncorrelated principal components that retain most of the information in the original dataset [9]. In groundwater contamination studies, PCA serves several critical functions:

(1) reducing the dimensionality of hydrogeochemical datasets, (2) identifying latent factors that explain observed variability, (3) associating specific contaminants with likely pollution sources, and (4) facilitating the interpretation of complex geochemical processes.

Rationale and Scope

Despite the proliferation of PCA applications in Nigerian groundwater studies, there has been no systematic evaluation of the methodology, its strengths, limitations, and the quality of its application. This gap is significant because the reliability of source apportionment directly influences remediation decisions, policy formulation, and resource allocation.

Misapplication or misinterpretation of PCA can lead to erroneous conclusions about contamination sources, potentially directing resources toward ineffective interventions.

This review aims to critically evaluate the application of PCA in groundwater contamination studies across Nigeria. The specific objectives are to:

1. Synthesize the existing literature on PCA applications in Nigerian groundwater quality studies
2. Evaluate methodological approaches, including data preprocessing, sampling design, and validation techniques
3. Identify common limitations and methodological shortcomings
4. Propose standardized protocols for PCA application in future studies
5. Identify knowledge gaps and priority areas for future research

MATERIAL AND METHODS

Literature Search Strategy

This review employed a systematic approach to identify relevant studies published between 2000 and 2026. The following databases were searched: Google Scholar, Scopus, Web of Science, and the African Journals Online (AJOL) database. Search terms included combinations of: "Principal Component Analysis," "PCA," "groundwater contamination," "groundwater quality," "Nigeria," "Niger Delta," "source apportionment," and "multivariate statistics." The search was limited to peer-reviewed journal articles, though relevant conference proceedings and technical reports were considered for contextual information.

Inclusion and Exclusion Criteria

Studies were included if they: (1) applied PCA to groundwater quality data from Nigerian locations, (2) reported sufficient methodological detail, (3) were published in English, and (4) focused on contamination assessment rather than purely hydrogeological characterization. Studies were excluded if they: (1) applied PCA only to surface water or soil data without groundwater components, (2) lacked clear methodological descriptions, or (3) were duplicates or preliminary reports superseded by full publications.

Data Extraction and Synthesis

From each included study, information was extracted on: study location, sample size, number of parameters analyzed, data preprocessing methods (e.g., normalization, transformation), PCA extraction criteria (e.g., eigenvalue threshold, scree plot), rotation methods, variance explained, interpretation approach, and validation techniques.

Findings were synthesized thematically, focusing on methodological patterns, common limitations, and reported outcomes.

OVERVIEW OF PCA APPLICATIONS IN NIGERIAN GROUNDWATER STUDIES

Geographic Distribution

The application of PCA in Nigerian groundwater contamination studies has been geographically uneven, with the Niger Delta region accounting for approximately 65% of published studies. This concentration reflects the region's status as the epicenter of oil exploration activities and associated environmental concerns. Studies in the Niger Delta have predominantly focused on petroleum hydrocarbon contamination, heavy metals, and the impacts of gas flaring [10,11].

In contrast, the southwestern region (including Lagos, Ogun, and Oyo states) accounts for approximately 20% of studies, primarily addressing urban groundwater contamination from industrial effluents, solid waste leachates, and domestic sewage [12,13].

The northern region has been relatively underrepresented, with most studies focusing on the Chad Basin and addressing salinity, fluoride, and nitrate contamination [14]. The southeastern region, aside from the oil-producing areas, has seen limited PCA applications despite significant groundwater quality challenges from mining and agricultural activities.

Contaminant Classes Investigated

The contaminant classes addressed by PCA studies in Nigeria can be categorized as follows:

Heavy Metals: This category dominates the literature, with studies typically analyzing 8–15 metals including lead, cadmium, chromium, copper, zinc, iron, manganese, and nickel. PCA has been employed to distinguish between geogenic and anthropogenic sources of these metals [15,16].

Petroleum Hydrocarbons: Studies in the Niger Delta have utilized PCA to identify oil spill impacts, differentiate between fresh and weathered hydrocarbons, and assess the contribution of gas flaring to groundwater contamination [17,18].

Physicochemical Parameters: Many studies incorporate basic parameters such as pH, electrical conductivity, total dissolved solids, temperature, and dissolved oxygen alongside contaminants to elucidate hydrochemical processes [19].

Nutrients and Inorganic Ions: Nitrate, phosphate, sulfate, chloride, and bicarbonate are frequently included to identify contributions from agricultural runoff, sewage, and natural weathering processes [20].

Emerging Contaminants: Very few studies have applied PCA to emerging contaminants such as pharmaceuticals, personal care products, or microplastics, representing a significant knowledge gap.

Sample Sizes and Study Designs

Reported sample sizes vary considerably, ranging from as few as 15 samples to over 200. The median sample size is approximately 45 samples.

The adequacy of these sample sizes for PCA application is questionable, as the technique typically requires a minimum ratio of 5–10 observations per variable [21].

Many reviewed studies fall below this threshold, potentially compromising the stability and reliability of extracted components.

CRITICAL EVALUATION OF METHODOLOGICAL APPROACHES

Sampling Design

A fundamental requirement for valid PCA is that samples are representative of the population of interest. The reviewed studies exhibit considerable variability in sampling design quality. The most robust studies employ systematic grid sampling across study areas, ensuring spatial representativeness [22]. However, many studies rely on purposive sampling focused on suspected contamination hotspots, which may introduce bias and limit the generalizability of results.

The vertical dimension of groundwater contamination is often inadequately addressed. Most studies sample only shallow groundwater from hand-dug wells or boreholes with limited depth documentation.

Few studies have investigated depth-dependent variations in contamination sources, which is particularly critical in understanding vertical transport mechanisms and aquifer vulnerability.

Data Preprocessing

Normality Assessment: PCA is not strictly distributional, but normality of variables influences the interpretability of results and the choice of extraction methods. Approximately 40% of reviewed studies report conducting normality tests (typically Kolmogorov-Smirnov or Shapiro-Wilk) before PCA application. Of these, many report non-normal distributions but proceed with standard PCA without appropriate transformations.

Data Transformation: The most commonly employed transformation is logarithmic transformation for positively skewed data, followed by standardization (z-scores) to eliminate the influence of different measurement units. However, approximately 30% of studies apply PCA directly to raw, untransformed, and unstandardized data, a practice that can lead to components dominated by variables with high variance or large measurement units (e.g., electrical conductivity compared to trace metals).

Outlier Treatment: The handling of outliers is inconsistently addressed. While some studies explicitly report outlier removal using methods such as box plots or Grubbs' test, many provide no information on outlier treatment, raising concerns about the influence of extreme values on component extraction.

Factor Extraction Criteria

The reviewed studies employ various criteria for determining the number of components to retain:

Eigenvalue > 1 (Kaiser Criterion): This is the most commonly used criterion, applied in approximately 70% of studies. While widely accepted, the Kaiser criterion is known to sometimes retain too many components when many variables have low communalities or too few when sample sizes are small.

Scree Plot: Approximately 55% of studies report using scree plots, often in combination with the eigenvalue criterion. However, the subjective interpretation of the scree plot's "elbow" is rarely justified or supported by parallel analysis.

Variance Explained: Many studies retain components that cumulatively explain 70–80% of total variance, but this criterion is often applied without consideration of variable communalities or the interpretability of components.

Parallel Analysis: This more rigorous criterion, which compares observed eigenvalues to those from random data, is employed in fewer than 10% of reviewed studies. Its absence is notable given its superiority over the eigenvalue criterion [23].

Rotation Methods

The choice of rotation method significantly influences component interpretability. Varimax rotation, which maximizes the variance of squared loadings and produces orthogonal (uncorrelated) components, is applied in approximately 60% of studies.

Oblique rotations (e.g., Promax, Direct Oblimin), which allow components to correlate, are used in less than 15% of studies. Approximately 25% of studies report no rotation, limiting interpretability.

The selection of rotation method should be guided by assumptions about underlying source relationships. Given that pollution sources are often correlated (e.g., industrial activities may contribute multiple contaminants), oblique rotations may be more appropriate in many contexts, yet they are rarely employed.

Component Interpretation

Interpretation of components is typically based on factor loadings, with thresholds for significant loadings ranging from 0.4 to 0.7. The most common approach is to consider variables with loadings exceeding 0.5 as significant contributors to a component. However, justification for threshold selection is rarely provided.

The assignment of component labels (e.g., "anthropogenic source," "geogenic source") is often subjective and unsupported by independent evidence. In many cases, authors infer sources based solely on the composition of variables loading on a component, without corroborating evidence such as land use analysis, historical contamination records, or isotopic tracers.

Validation

A critical weakness in the reviewed literature is the lack of validation for PCA results. Fewer than 5% of studies employ any form of validation, such as split-sample validation, bootstrapping, or comparison with independent source data. This absence raises questions about the stability and generalizability of reported component structures.

KEY FINDINGS FROM PCA APPLICATIONS

Source Apportionment in the Niger Delta

PCA studies in the Niger Delta have consistently identified three to five principal components that distinguish between:

1. Petroleum hydrocarbon contamination: Components loading heavily on total petroleum hydrocarbons, volatile organic compounds, and specific PAHs
2. Heavy metals from oil-related activities: Components characterized by vanadium, nickel, lead, and cadmium
3. Geogenic influences: Components dominated by iron, manganese, and hardness parameters
4. Salinity intrusion: Components with high loadings of chloride, sodium, and electrical conductivity
5. Nutrient pollution: Components associated with nitrate, phosphate, and ammonia

The consistency of these findings across multiple studies supports the validity of PCA for distinguishing contamination sources in this region. However, the differentiation between natural background levels and anthropogenic contamination remains challenging, particularly for metals with both geogenic and anthropogenic sources.

Urban Groundwater Studies

In urban areas, PCA has revealed the complexity of contamination sources, with studies typically identifying components representing:

1. Domestic sewage: High loadings of nitrate, phosphate, chloride, and coliform bacteria
2. Industrial effluents: Components dominated by heavy metals specific to local industries
3. Solid waste leachates: Associations between heavy metals, ammonia, and organic indicators
4. Natural hydrochemistry: Components related to geological weathering processes

Studies in Lagos have demonstrated the utility of PCA in distinguishing between seasonal variations in contamination sources, with wet season components reflecting surface runoff contributions and dry season components dominated by groundwater interaction with contaminated sediments [12].

Agricultural Contamination

PCA applications in agricultural regions have identified components associated with:

1. Fertilizer application: Nitrate, phosphate, potassium, and sometimes sulfate
2. Pesticide use: Organochlorine and organophosphate compounds (limited studies)
3. Natural soil chemistry: Calcium, magnesium, and bicarbonate from carbonate weathering
4. Livestock operations: Ammonia, nitrate, and microbial indicators

Temporal Patterns

Few studies have employed PCA to investigate temporal patterns in groundwater contamination. Those that have conducted seasonal analyses consistently report differences in component structures between wet and dry seasons, reflecting the influence of recharge processes, dilution, and contaminant transport mechanisms [19].

METHODOLOGICAL LIMITATIONS AND CRITICAL ISSUES

Inadequate Sample Sizes

The most pervasive limitation across reviewed studies is inadequate sample size relative to the number of variables analyzed. The Kaiser-Meyer-Olkin (KMO) measure of

sampling adequacy is reported in fewer than 40% of studies, and many studies with KMO values below the recommended threshold (>0.6) proceed with PCA. This practice risks extracting unstable components that may not replicate in independent samples.

Lack of Validation

The near-absence of validation techniques severely limits confidence in reported results. Without validation, it is impossible to determine whether extracted components represent stable, replicable patterns or are artifacts of the specific dataset analyzed.

Over-interpretation

Many studies over-interpret PCA results, attributing components to specific contamination sources without supporting evidence. The technique identifies statistical associations, not causal relationships. Components may represent combinations of sources, non-linear interactions, or artifacts of sampling design. Confirmation of source assignments requires independent evidence from land use analysis, hydrogeological investigations, or targeted chemical analyses (e.g., isotopic ratios).

Neglect of Censored Data

Contaminant datasets frequently contain values below detection limits. The treatment of such censored data is rarely addressed, with common practices including deletion of variables with many non-detects, substitution with half the detection limit, or replacement with zero. Each approach introduces bias, yet specialized methods for PCA with censored data (e.g., multiple imputation, robust PCA) are seldom employed.

Geographic and Contaminant Gaps

The concentration of PCA studies in the Niger Delta and southwestern Nigeria leaves vast geographic areas unexplored. The northern region, with its unique hydrogeological characteristics and distinct contamination pressures, remains understudied.
Similarly, emerging contaminants such as pharmaceuticals, microplastics, and per- and polyfluoroalkyl substances (PFAS) have not been addressed through PCA in Nigerian groundwater studies.

RECOMMENDED PROTOCOLS FOR PCA APPLICATION

Based on the critical evaluation of existing studies and established best practices, the following protocols are recommended for future PCA applications in Nigerian groundwater contamination studies:

Study Design

• Sample size: Ensure minimum ratio of 5–10 observations per variable, with absolute minimum of 50 samples for stable PCA

- Sampling strategy: Employ systematic sampling with spatial stratification, including background reference sites
- Vertical sampling: Include samples from multiple depths to assess vertical transport
- Temporal sampling: Conduct seasonal sampling to assess temporal variability

Data Preprocessing

- Normality assessment: Report normality tests and apply appropriate transformations (log, Box-Cox) for non-normal variables
- Standardization: Always apply standardization (z-scores) to variables measured in different units
- Outlier treatment: Report outlier identification methods and justify any removal or transformation
- Censored data: Apply appropriate methods (e.g., multiple imputation, robust PCA) for values below detection limits

Factor Extraction

- Multiple criteria: Use multiple extraction criteria (e.g., parallel analysis, eigenvalue >1, scree plot, variance explained) and report results from all
- Parallel analysis: Employ parallel analysis for rigorous determination of component retention
- Communalities: Report variable communalities to assess the adequacy of component solutions

Rotation

- Justify rotation: Clearly justify the choice of rotation method based on assumptions about source correlations
- Consider oblique rotation: Use oblique rotation when correlated sources are anticipated
- Report rotation: Clearly state rotation method and any parameters employed

Interpretation

- Loadings threshold: Specify threshold for significant loadings (typically 0.5–0.7) and justify
- Source assignment: Support source assignments with independent evidence (land use, historical data, hydrogeological information)
- Confidence statements: Use appropriate language acknowledging the inferential nature of source identification

Validation

- Split-sample validation: Validate results on independent subsets of data where possible
- Bootstrapping: Employ bootstrapping to assess component stability

• Sensitivity analysis: Conduct sensitivity analyses to assess the impact of preprocessing decisions

Reporting

• Complete documentation: Report KMO, Bartlett's test, eigenvalues, loadings, communalities, and variance explained
• Supplementary information: Provide full loading matrices and scree plots in supplementary materials
• Data availability: Consider making datasets available to facilitate replication and meta-analysis

FUTURE RESEARCH DIRECTIONS

Integration with Geospatial Techniques

The integration of PCA with Geographic Information Systems (GIS) and geostatistical methods offers significant potential for advancing groundwater contamination studies. Future research should explore:
• Spatial PCA: Incorporating spatial autocorrelation into PCA
• PCA with geostatistical mapping: Visualizing the spatial distribution of component scores
• Land use regression: Combining PCA results with land use analysis for source attribution

Advanced Multivariate Methods

While PCA provides valuable insights, its limitations suggest the need for complementary approaches:
• Positive Matrix Factorization (PMF): This receptor model provides more robust source apportionment than PCA, particularly for datasets with many non-detects
• Machine learning approaches: Random forests, support vector machines, and neural networks may reveal non-linear relationships not captured by PCA
• Bayesian methods: Probabilistic approaches can incorporate prior information and quantify uncertainty in source assignments

Emerging Contaminants

The application of PCA to emerging contaminants represents a critical research frontier:
• Pharmaceuticals and personal care products: Investigate sources and transport mechanisms
• Microplastics: Explore associations with traditional contaminants
• PFAS: Characterize distribution and potential sources in groundwater

Regional Synthesis

The development of regional-scale PCA studies could address gaps in geographic coverage and facilitate comparative analyses:

- Sedimentary basin studies: Systematically characterize groundwater quality across Nigeria's major basins
- Transboundary aquifers: Investigate contamination sources in shared groundwater resources
- National database: Develop a centralized database of groundwater quality data to support regional PCA applications

Climate Change Considerations

Future studies should consider the implications of climate change for groundwater contamination:

- Seasonal shifts: Investigate how changing precipitation patterns influence contaminant transport
- Sea level rise: Assess impacts on saltwater intrusion and associated contaminant mobilization
- Extreme events: Characterize the role of flooding and drought in contaminant redistribution

CONCLUSIONS

This critical review evaluates the application of Principal Component Analysis (PCA) in groundwater contamination+6 ++n studies across Nigeria, synthesizing findings from research conducted over the past two decades. The analysis indicates that, although PCA has become a well-established tool for source apportionment—particularly in the Niger Delta—its use is marked by considerable methodological inconsistency and notable limitations.

Key issues identified include inadequate sample sizes, insufficient data preprocessing, inconsistent component extraction criteria, lack of validation procedures, and the over-interpretation of results. Collectively, these shortcomings undermine the reliability of source identification and constrain the practical utility of PCA outcomes for environmental management.

Notwithstanding these limitations, PCA has demonstrated effectiveness in differentiating contamination sources, especially in regions characterized by complex pollution histories. The recurrence of similar component structures across multiple studies in the Niger Delta lends support to the method's validity in distinguishing petroleum-related contamination from geogenic influences and other anthropogenic inputs.

To advance the field, this review advocates for the adoption of standardized protocols for PCA application, with particular emphasis on rigorous study design, appropriate data preprocessing, robust extraction criteria, and, critically, systematic validation of results. Future research should expand the application of PCA to underexplored regions and contaminant categories, integrate PCA with geospatial techniques and advanced multivariate approaches, and address emerging challenges associated with climate change and novel contaminants.

Ultimately, the objective of PCA applications in Nigerian groundwater studies should be to generate reliable evidence for source attribution that can guide targeted remediation strategies, support evidence-based policy development, and contribute to the protection of groundwater resources vital to public health and sustainable development. Achieving this objective requires not only methodological rigor but also a strong commitment to transparency, reproducibility, and the integration of statistical analyses with domain-specific knowledge of hydrogeology, land use, and contaminant dynamics.

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KRITIČKI PREGLED PRIMENE ANALIZE GLAVNIH KOMPONENTI U ISTRAŽIVANJU ZAGAĐENJA PODZEMNIH VODA U NIGERIJI

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Sažetak: Podzemne vode i dalje predstavljaju najpouzdaniji izvor vode za piće u Nigeriji, naročito u ruralnim i prigradskim područjima.

Međutim, rastuće antropogene aktivnosti - od eksploatacije nafte i industrijskih otpadnih voda do loših poljoprivrednih praksi i neadekvatnog odlaganja različitih vrsta otpada - značajno su povećale pritisak i zagađenja na ovaj vitalni resurs.

Analiza glavnih komponenti (PCA- Principal Component Analysis) nametnula se kao moćan multivarijantni statistički alat za identifikaciju različitih izvora zagađenja, razumevanje puteva kretanja zagađujućih-štetnih materija i interpretaciju složenih hidrogeohemijskih skupova podataka.

Ovaj rad daje kritički pregled primene PCA (Principal Component Analysis= Analiza Glavnih Komponeneti) u istraživanjima zagađenja podzemnih voda širom Nigerije, sintetišući nalaze iz recenzirane naučne literature u poslednje dve decenije.

U radu se analiziraju metodološki pristupi, identifikuju uobičajena ograničenja i procenjuje efikasnost PCA u uzrocima izvora zagađenja vode kao važnog resura.

Ključni nalazi ukazuju da, iako je PCA široko primenjivana u regionu delte Nigera u istraživanjima zagađenja naftnim ugljovodonicima, njena primena u drugim regionima i za druge klase zagađujućih materija (npr. teški metali, nitrati, farmaceutski spojevi) ostaje ograničena. Uobičajeni metodološki nedostaci uključuju neadekvatnu pripremu podataka, nedovoljan broj uzoraka, izostanak validacije i preteranu interpretaciju komponenti.

Analiza rezultata u radu predlaže standardizovane protokole za primenu PCA (Principal Component Analysis - Analiza Glavnih Komponeneti) u istraživanjima podzemnih voda u Nigeriji i identifikuje prioritetne pravce budućih istraživanja, uključujući integraciju PCA sa geoprostornim tehnikama i pristupima zasnovanim na mašinskom učenju i veštačkoj inteligenciji .

Rezultati naglašavaju potrebu za rigoroznijom statističkom praksom kako bi se povećala pouzdanost identifikacije izvora zagađenja i podržalo donošenje politika upravljanja podzemnim vodama zasnovanih na dokazima u Nigeriji.

Ključne reči: *Analiza glavnih komponenti, zagađenje podzemnih voda, Nigerija, atribucija (značenje) izvora, multivarijantna statistika, hidrogeohemija*.

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