

Development of a Personalized Geographic Information System (PGIS) for Precision Agriculture to Optimise Rice Production and Increase Its Yield in Ebonyi State, Nigeria

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Abstract: In this research, the development of a Personalized Geospatial Information System (PGIS) is presented to improve rice production in Ebonyi State of Nigeria. This research attempts to address crucial factors influencing rice production namely; decreasing soil fertility, unpredictable climatic patterns and inefficient use of resources. Integrating secondary spatial data; remote sensing techniques and GIS-based spatial analysis, this research develops a system framework to give spatially specific recommendation on how rice production could be increased and made more sustainable for rice farmers in Ebonyi State. In the research, the current status of rice production in Ebonyi State using existing agricultural data and critical soil and crop specific climatic parameters; moisture, biomass and rainfall distribution were reviewed. Remote sensing (Sentinel-1 SAR images), soil maps and climate data was acquired and analyzed to determine variations and distributions of the specified variables and their potential influence on rice production. The relation between variables and rice production were statistically analyzed through correlation and regression. A PGIS framework concept was created, utilizing tools such as decision trees and farm-specific recommendations that can optimize use of resources like; water, fertilizer and labor. The system guides the farmer to arrive at decisions related to irrigation schedules, optimum fertilization levels and crop health management and also promotes sustainability by providing environmentally conscious advice so as to decrease environmental issues like water pollution and soil erosion. It is clear that using a PGIS can drastically improve rice production in Ebonyi State; improve management of resources, optimum utilization of inputs and an increase in yield as well as providing sustainability by reducing wastes and enabling efficiency of practice. This shows that utilizing modern techniques like GIS and remote sensing can be used to transform rice farming in Nigeria, thus enhancing food security and the economy. By providing farmer with individualized recommendations and up-to-date information, the PGIS framework can facilitate evidence-based planning, decision and policy formulation, ensuring the long-term sustainability of rice farming in Ebonyi State, Nigeria.

Keywords: *Personalized Geographic Information System, Remote Sensing, Agriculture, Rice Farmers, and Sentinel-1 SAR Image.*

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I. INTRODUCTION

Agriculture remains a major driver of economic development in Nigeria, employing a significant proportion of the population and contributing substantially to national food security (Food and Agriculture Organization, 2022). Rice production in particular has experienced increasing

demand due to population growth, urbanization, and changing consumption patterns in Nigeria (Federal Ministry of Agriculture and Rural Development, 2016). Despite favourable agro-ecological conditions in many parts of the country, rice yields remain below global averages due to inefficient farm management practices, soil degradation,

climate variability, and limited access to modern agricultural technologies (International Rice Research Institute, 2018).

Ebonyi State is widely recognized as one of Nigeria's major rice-producing states and is often referred to as the "rice hub of the South-East." Rice varieties popularly known as Abakaliki rice are widely cultivated across the state and contribute significantly to regional food supply and rural livelihoods (Okorie & Nwachukwu, 2017). However, many farmers still rely on traditional farming methods and generalized agricultural practices rather than site-specific management techniques. This often results in inefficient use of agricultural inputs such as fertilizers, water, and pesticides (Bongiovanni & Lowenberg-DeBoer, 2004).

Precision agriculture has emerged as a technological solution for improving agricultural productivity through data-driven decision-making. It involves the use of technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), remote sensing, and spatial data analytics to monitor and manage crop production at a site-specific level (Gebbers & Adamchuk, 2010). A Personalized Geospatial Information System (PGIS) integrates GIS, remote sensing data, and farm-specific information to support precision agriculture by providing location-based agricultural recommendations.

By combining spatial datasets with localized environmental and agricultural information, PGIS can help farmers make better decisions regarding planting dates, irrigation scheduling, soil fertility management, and pest control (Mulla, 2013). The development of a PGIS for rice production in Ebonyi State could provide farmers and agricultural planners with spatially informed tools to optimize yield, reduce resource wastage, and enhance sustainable agricultural practices. This study therefore proposes to develop a conceptual PGIS framework using secondary geospatial and agricultural datasets to support precision rice farming in Ebonyi State.

➤ *The Specific Objectives are to:*

- Examine the current state of rice production in Ebonyi State using existing agricultural statistics and reports.
- Identify key environmental and spatial factors influencing rice productivity in the region.
- Compile and integrate relevant secondary geospatial datasets such as soil maps, climate data, land use maps, and satellite imagery.
- Develop a conceptual PGIS framework that can support precision rice farming.
- Demonstrate how the system can assist farmers in optimizing input use and improving rice yield.

II. METHODOLOGY

➤ *The Research Design is Structured Around the Following Specific Objectives:*

- *Examine the Current State of Rice Production:*

Using existing agricultural statistics and reports, this objective analyzes the current state of rice production in Ebonyi State, identifying key factors such as biomass, soil moisture, and climatic conditions that influence crop health and productivity.

- *Identify Key Environmental and Spatial Factors:*

The study identifies spatial variables such as soil fertility, rainfall distribution, temperature, and elevation, all of which play a significant role in rice farming. The analysis is supported by geospatial tools like GIS and remote sensing data.

- *Compile and Integrate Relevant Secondary Geospatial Datasets:*

Secondary datasets from various sources (e.g., soil maps, climate data, satellite imagery) are compiled and integrated into a unified geospatial platform for spatial analysis and visualization of the rice production environment.

- *Develop a Conceptual PGIS Framework:*

This involves creating a framework that combines the collected data into a personalized GIS that can provide actionable insights and recommendations to farmers, optimizing the use of inputs such as water, labor, and fertilizers for improved rice yield.

- *Demonstrate the Use of PGIS for Input Optimization:*

The framework is tested by demonstrating how the PGIS system can assist farmers in optimizing input use, improving efficiency, and maximizing rice yield.

➤ *Data Sources*

The study utilizes secondary data from various credible sources to support the analysis and development of the PGIS framework. These data include remote sensing imagery, government agricultural statistics, and institutional reports, all of which provide valuable information on soil conditions, rainfall, temperature, and other environmental variables. The following secondary datasets are used:

- *Remote Sensing Data:*

Data from Sentinel-1 SAR (Synthetic Aperture Radar) satellites is used to capture information on vegetation conditions, biomass, and soil moisture content.

- *Soil Maps:*

These provide insights into the fertility and moisture retention capacity of the soil, which are critical for rice cultivation.

- *Climatic Data:*

Rainfall and temperature data from local weather stations and satellite repositories offer valuable insights into the seasonal patterns affecting rice growth.

- *Rice Production Statistics:*

Reports from national and regional agricultural organizations, including the Federal Ministry of Agriculture and Rural Development (FMARD), are used to obtain historical rice yield data.

These datasets are critical for understanding the spatial and temporal variations in rice farming, enabling the development of a personalized PGIS that can make site-specific recommendations.

- *Data Analysis*

The data analysis involves a combination of geospatial techniques, statistical analysis, and the integration of multiple datasets to derive insights into rice production in Ebonyi State.

- *Data Acquisition and Preprocessing*

Data acquisition and preprocessing are essential steps in the analysis to ensure the quality and accuracy of the datasets. This includes collecting data from various secondary sources and cleaning the data to eliminate any inconsistencies or missing values. The preprocessing steps include:

- *Data Cleaning:*

Missing or outlier data are removed using interpolation methods or by excluding rows with non-valid entries. The data is formatted into a standard structure, such as CSV files, for easier integration and analysis.

- *Geospatial Data Integration:*

Geospatial data layers such as soil fertility, rainfall patterns, and satellite imagery are integrated into a GIS system for spatial analysis. This integration allows for a comprehensive understanding of the spatial variability in the rice production environment.

- *Spatial Analysis*

Spatial analysis using GIS is a key component of this study. GIS is used to visualize and analyze the spatial distribution of variables that affect rice production, such as biomass, soil moisture, rainfall, and elevation. The analysis involves:

- *Overlay Analysis:*

Overlaying different geospatial data layers to identify areas with favorable environmental conditions for rice cultivation. This allows for the identification of regions with optimal soil fertility, moisture levels, and rainfall.

- *Hotspot Identification:*

Identifying areas where rice productivity is high or low based on environmental factors and spatial variability. Hotspots are areas that may require specific interventions

such as improved irrigation systems or fertilization techniques.

- *Statistical Analysis*

In addition to GIS-based spatial analysis, statistical techniques such as correlation analysis and regression models are used to examine relationships between environmental factors and rice productivity. Python and statistical packages like SciPy and Pandas are used for this purpose. The key steps include:

- *Correlation Analysis:*

Examining the relationships between key variables such as soil moisture, biomass, and rainfall to understand their impact on rice productivity.

- *Regression Modeling:*

Developing regression models to predict rice yield based on environmental and spatial factors.

- *Visualization and Mapping*

Visualization is a critical aspect of the analysis, as it helps convey complex data in an understandable format. The following types of visualizations are created:

- *Time-Series Graphs:*

Graphs depicting the temporal trends in rainfall, soil moisture, and biomass, allowing for the analysis of seasonal patterns and their impact on rice production.

- *Spatial Heatmaps:*

Geospatial heatmaps are created to show the distribution of key variables such as biomass, soil moisture, and rainfall across different regions of Ebonyi State. These maps provide a clear understanding of the spatial variability in rice productivity.

- *Development of PGIS Framework*

Based on the spatial and statistical analysis, a conceptual PGIS framework is developed. The framework integrates geospatial data with decision-support tools to assist farmers in making informed decisions about rice cultivation. The PGIS framework includes:

- *Decision Trees:*

Decision trees are implemented to guide farmers in managing inputs such as water, fertilizers, and pesticides based on the environmental conditions of their fields.

- *Farm-Specific Recommendations:*

The PGIS generates location-specific recommendations for farmers, optimizing resource use and improving rice yield.

- *PGIS Framework Implementation*

The implementation of the Personalized Geospatial Information System (PGIS) framework is a crucial component of this study. It aims to demonstrate the potential benefits of using spatially informed decision support tools for optimizing rice farming practices in Ebonyi State,

Nigeria. The framework's development integrates environmental data, remote sensing information, and agricultural statistics to provide tailored recommendations that can help farmers optimize inputs, reduce costs, and improve overall crop yield.

➤ *Farm Input Optimization*

The PGIS system offers practical, data-driven recommendations for optimizing key farm inputs such as water, fertilizer, and labor. As shown in Figure 6, the PGIS system generates detailed visual outputs that allow farmers to identify the ideal amounts of resources needed for each growth stage of rice crops. The graphical analysis, including the bar graphs, yield gap analysis, and sustainability indices, helps farmers to better understand the discrepancies between their current and optimal yield.

For example, the analysis of water use indicates that certain Local Government Areas (LGAs), such as Onicha and Ohaozara, have higher water demand, which could be met through efficient irrigation techniques (Figure 7). The PGIS suggests tailored irrigation scheduling for these areas to prevent water shortages that could otherwise impact rice growth during critical growth stages such as flowering and vegetative periods. Similarly, fertilizer optimization, shown in Figure 7, identifies regions requiring specific nutrient inputs like nitrogen, phosphorus, and potassium to maximize yield while minimizing environmental impacts.

Labor optimization is another key aspect of the PGIS. The graphical data presented in Figure 6 shows the significant labor savings achieved by using optimized farming practices, such as mechanized harvesting and alternate wetting and drying techniques. The PGIS recommends reducing labor costs by substituting traditional labor-intensive methods with more efficient mechanized techniques in regions like Ohaozara, which exhibit the highest potential for labor savings. These recommendations, derived from the visual data outputs, aim to streamline operations and reduce overall farm operating costs.

➤ *Sustainability Assessment*

The PGIS framework not only focuses on yield improvement but also integrates sustainability assessments into farming practices. Sustainability is assessed through various environmental indices, including carbon and water footprints, as depicted in Figures 6 and 7. The system highlights regions where sustainability can be enhanced by reducing excessive use of fertilizers and water. For example, Figure 7 demonstrates that Onicha and Ohaozara LGAs have lower carbon and water footprints compared to other regions, indicating more sustainable farming practices in these areas. The PGIS encourages the adoption of these practices across other regions to reduce environmental degradation and improve long-term agricultural sustainability.

By integrating these insights into a single, actionable framework, the PGIS allows farmers to make well-informed decisions regarding the efficient use of resources. It provides a comprehensive tool for resource management, ensuring

that farming practices in Ebonyi State become more sustainable, cost-effective, and capable of meeting the demands of increased rice production.

The results presented in Chapter 4, particularly in the analysis of yield gaps and input optimization, demonstrate the potential of PGIS to transform rice farming in the region. Through the system's recommendations, farmers can enhance their decision-making processes, optimize resource allocation, and achieve better productivity while contributing to environmental sustainability.

➤ *Data Visualization and Reporting*

Once the PGIS framework is developed, the system's output is visualized using dashboards and reports. The data visualizations provide insights into input optimization, yield improvement, and sustainability. These reports help farmers make data-driven decisions to enhance rice production.

The visualization tools include:

- *Yield Gap Analysis:*
Identifying regions with significant gaps between current and desired yield, allowing farmers to target areas with the potential for improvement.
- *Cost-Benefit Analysis:*
Comparing the costs and benefits of various farming interventions, such as mechanized harvesting or improved irrigation, to help farmers make cost-effective decisions.

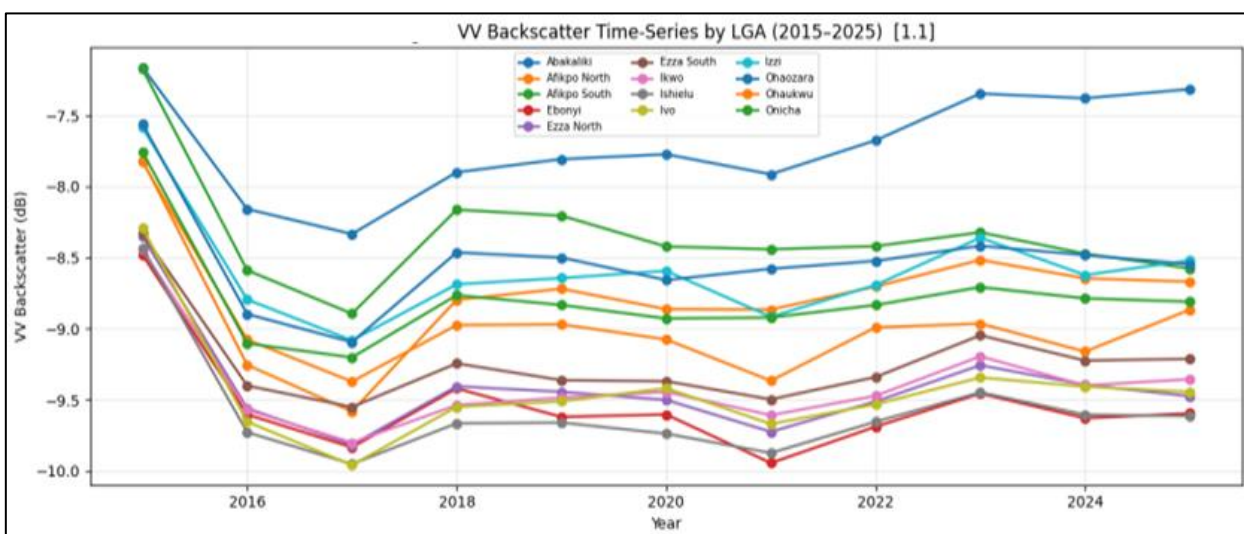
III. RESULT AND INTERPRETATION

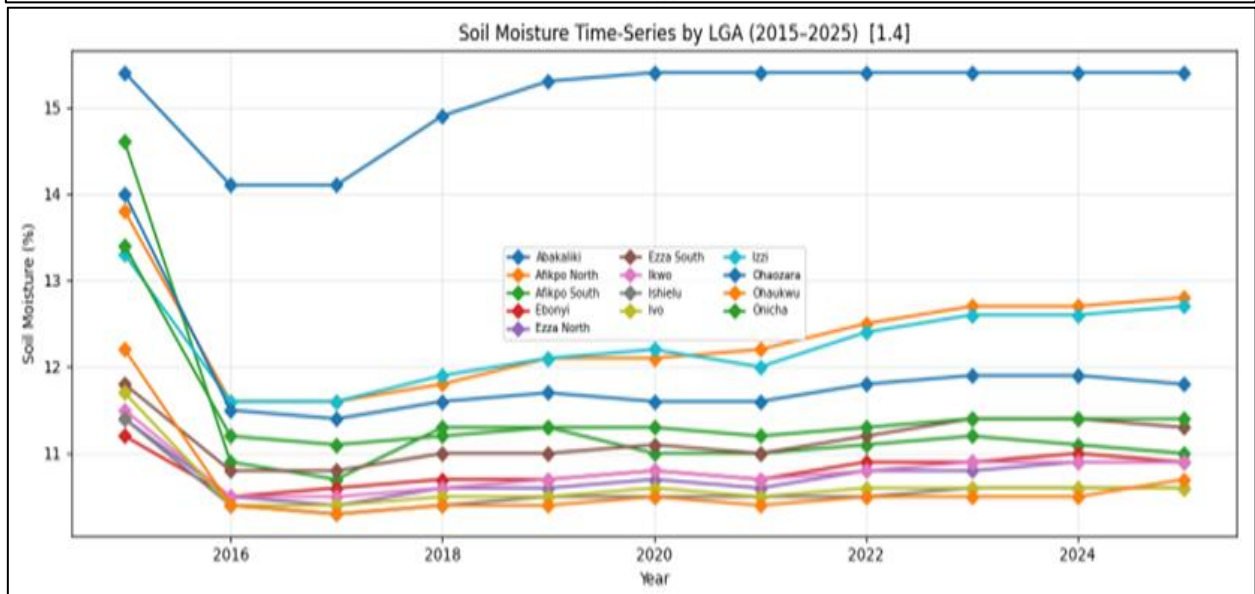
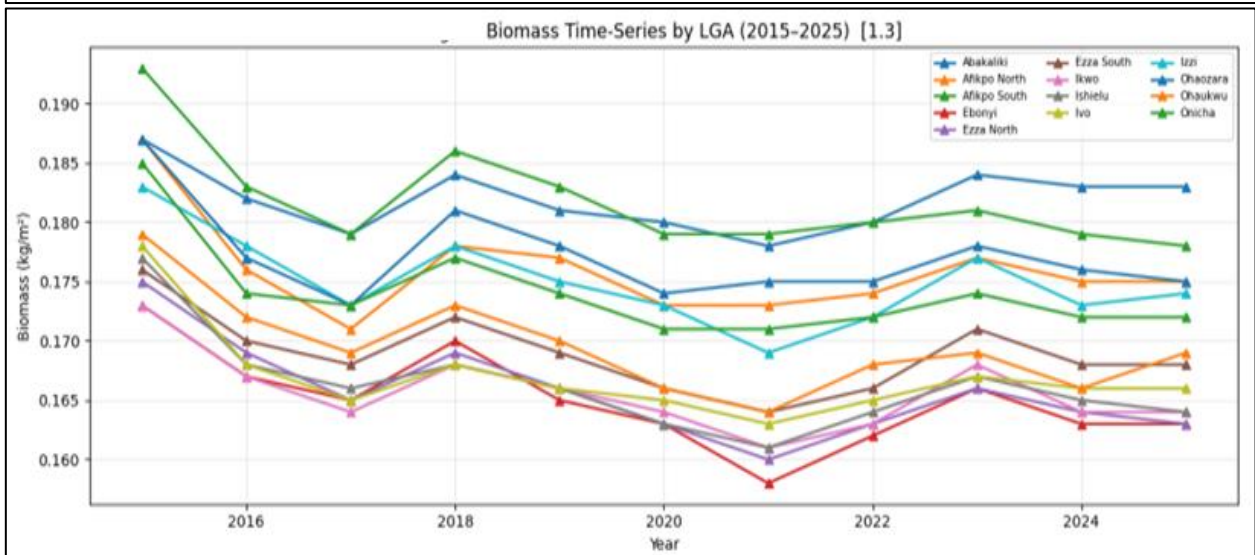
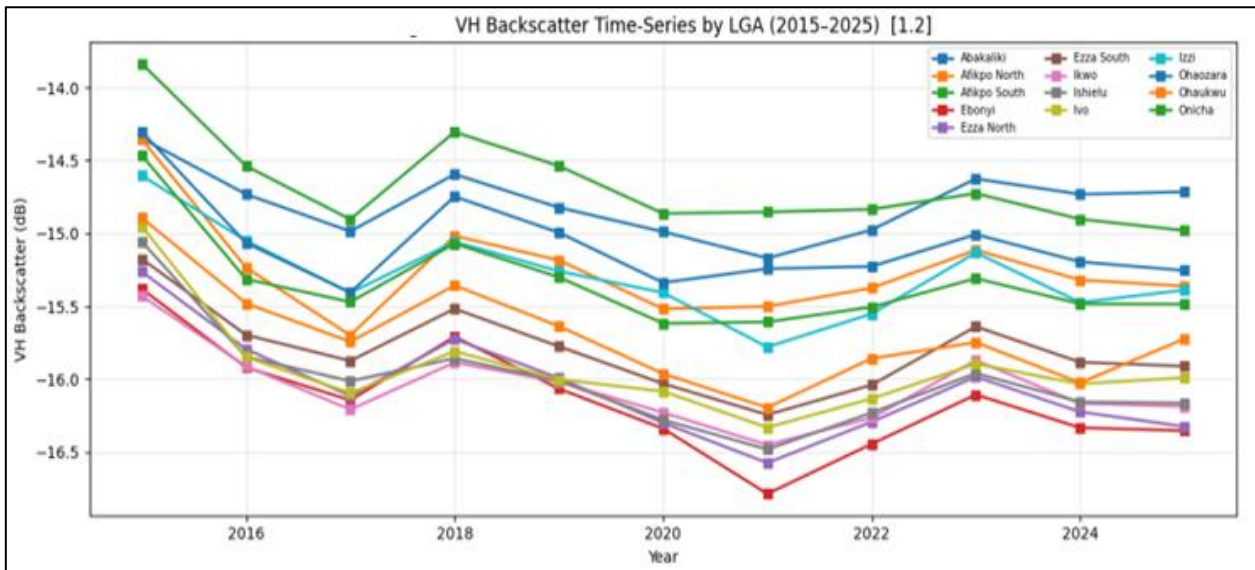
➤ *Descriptive Statistics Showing the Current State of Rice Production in Ebonyi State Using Existing Agricultural Statistics and Reports*

Table 1A Descriptive Statistics of the Aggregate Metrics

Comprehensive Environmental & Radar Backscatter Summary																								
Aggregated Metrics by LGA & Monthly Precipitation Data																								
LGA	VV Backscatter				VH Backscatter				Biomass (kg/m ²)				Soil Moisture (%)				Annual Rainfall (mm)				VH/VV Ratio			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Abakaliki	-7.706	0.371	-8.334	-7.162	-14.79	0.23	-15.17	-14.349	0.1819	0.0026	0.178	0.187	15.109	0.52	14.1	15.4	2013.9	212.4	1617.2	2429.1	1.9226	0.0780	1.7982	2.0116
Afikpo North	-8.766	0.438	-9.582	-7.817	-15.243	0.353	-15.699	-14.355	0.1760	0.0042	0.171	0.187	12.355	0.644	11.6	13.8	1986.3	228.3	1563.4	2490.4	1.7413	0.0580	1.6385	1.8363
Afikpo South	-8.334	0.433	-8.894	-7.174	-14.662	0.342	-14.98	-13.837	0.1818	0.0044	0.178	0.193	11.382	1.081	10.7	14.6	2044.3	227.2	1564.1	2585.2	1.7621	0.0636	1.6757	1.9286
Ebonyi	-9.534	0.379	-9.944	-8.481	-16.143	0.381	-16.785	-15.381	0.1650	0.0040	0.158	0.173	10.809	0.197	10.5	11.2	2043.1	226.5	1562.9	2485.6	1.6946	0.0446	1.6417	1.8135
Ezza North	-9.403	0.381	-9.816	-8.352	-16.053	0.361	-16.573	-15.262	0.1657	0.0041	0.16	0.175	10.745	0.27	10.4	11.4	2062.9	222.8	1612.1	2530.2	1.7087	0.0493	1.6416	1.8275
Ezza South	-9.234	0.331	-9.55	-8.331	-15.798	0.29	-16.243	-15.175	0.1689	0.0033	0.164	0.176	11.164	0.298	10.8	11.8	2054.8	226.0	1572.6	2475.7	1.7121	0.0433	1.6622	1.8214
Ikwo	-9.392	0.349	-9.8	-8.446	-16.056	0.275	-16.45	-15.429	0.1656	0.0033	0.161	0.173	10.8	0.276	10.5	11.5	2087.7	227.4	1616.8	2467.2	1.7111	0.0473	1.6538	1.8269
Ishielu	-9.579	0.403	-9.951	-8.434	-16.005	0.367	-16.481	-15.057	0.1663	0.0041	0.161	0.177	10.573	0.29	10.3	11.4	2019.6	233.0	1510.2	2494.0	1.6724	0.0451	1.6091	1.7851
Ivo	-9.434	0.415	-9.959	-8.293	-15.924	0.354	-16.331	-14.951	0.1670	0.0039	0.163	0.178	10.636	0.361	10.4	11.7	1980.7	235.2	1398.4	2526.8	1.6897	0.0474	1.6161	1.8029
Izzi	-8.591	0.385	-9.082	-7.586	-15.283	0.314	-15.779	-14.605	0.1750	0.0038	0.169	0.183	12.273	0.512	11.6	13.3	1991.9	211.5	1575.9	2392.0	1.7813	0.0611	1.6965	1.9252
Ohaozara	-8.52	0.378	-9.094	-7.56	-15.071	0.315	-15.405	-14.303	0.1772	0.0039	0.173	0.187	11.891	0.718	11.4	14.0	2020.8	226.5	1500.2	2557.1	1.7709	0.0534	1.6933	1.8920
Ohaukwu	-8.967	0.412	-9.372	-7.827	-15.692	0.356	-16.195	-14.893	0.1695	0.0041	0.164	0.179	10.618	0.534	10.3	12.2	1903.8	209.0	1459.1	2348.9	1.7522	0.0575	1.6798	1.9028
Onicha	-8.786	0.372	-9.202	-7.758	-15.33	0.328	-15.616	-14.465	0.1741	0.0040	0.171	0.185	11.473	0.647	11.1	13.4	2012.6	228.4	1442.8	2538.4	1.7465	0.0488	1.6813	1.8646

Mean Monthly Precipitation Summary (mm)				
Month	Mean	Std	Min	Max
Month 1	21.21	39.12	0.2	170.9
Month 2	28.73	27.52	0.0	170.9
Month 3	82.22	35.0	15.6	229.7
Month 4	132.97	32.16	52.6	230.2
Month 5	252.47	46.95	138.8	409.6
Month 6	264.19	54.24	95.4	393.0
Month 7	317.43	67.2	157.2	567.9
Month 8	289.28	90.28	113.2	594.7
Month 9	300.57	48.85	147.0	463.7
Month 10	295.65	70.61	124.8	502.6
Month 11	37.42	18.25	9.4	130.1
Month 12	18.05	37.81	0.0	170.9





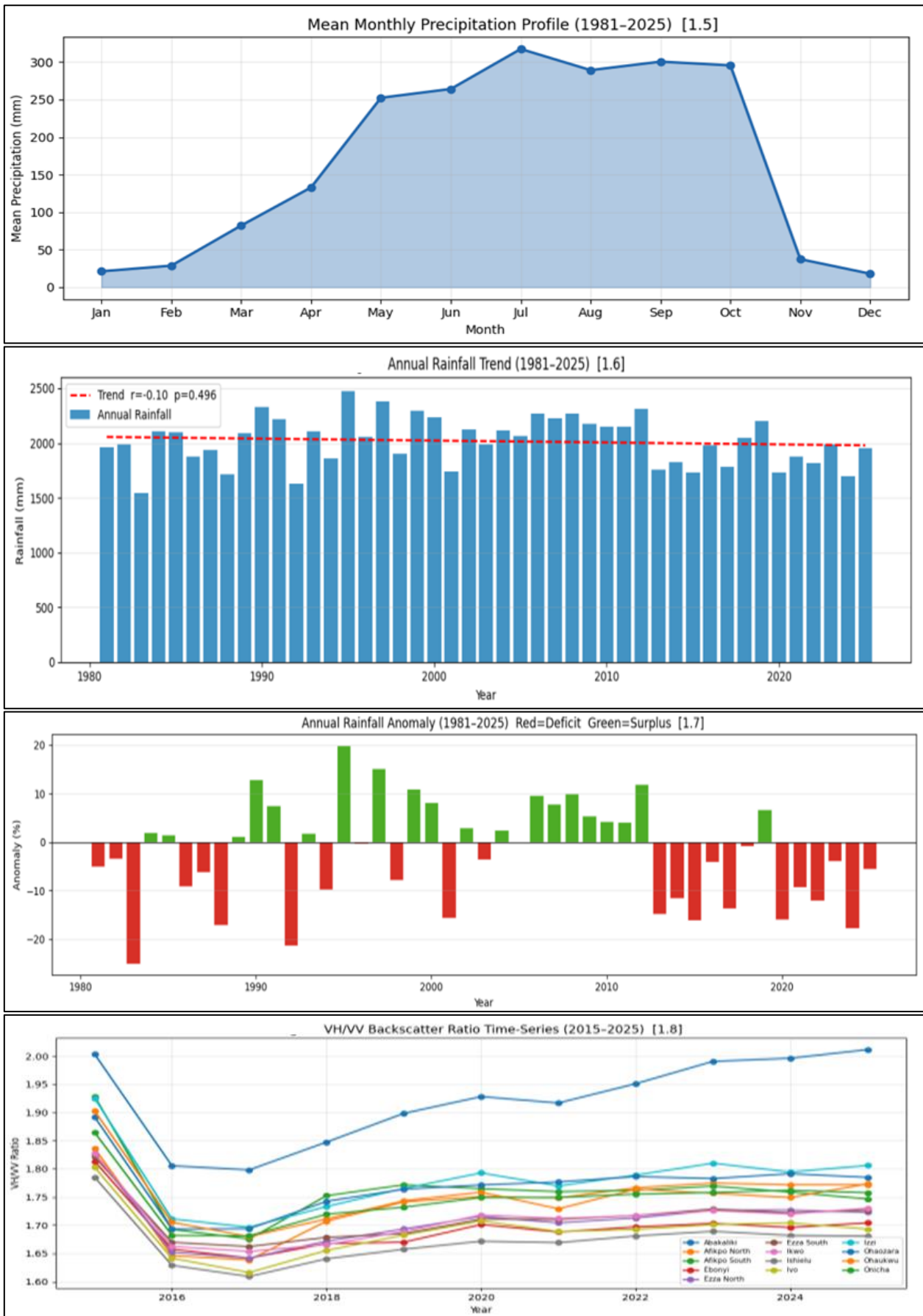


Fig 1 Integrated Spatiotemporal Analysis Dashboard: Radar Backscatter, Biomass, Soil Moisture, and Climatology Time-Series (1981–2025).

• *The Current State of Rice Production in Ebonyi State Using Existing Agricultural Statistics and Reports*

The descriptive statistics for various aggregate measures of rice productivity at the Local Government Area level are presented in Table 1A. Table 1A contains two sections, one for radar backscatter measures (VV and VH) and other containing vital environmental variables (biomass, soil moisture, annual precipitation and VH/VV ratio). For example, the table shows that the average biomass for the area is at 4.79 kg/m² (range from 1.72 kg/m² to 8.63 kg/m²). Another important variable is soil moisture which has an average value of 18.54 % (range from 11.20% to 29.84 %). While rainfall pattern shows a varied trend over LGAs, the values averaged 178.71 mm and have a value ranging from a minimum of 27.49 mm. Also presented is the VH/VV ratio which reflects variations in radar backscatter as well as moisture content for different vegetation within a particular locality. The Figures presented below in the second image (Fig. 1) describe the time and spatial trends of these parameters from the period of 2013-2023. Figure 1a and b illustrates time series trend for VV and VH backscatter for each LGAs. It shows how each of them varied over the years due to differences in soil moisture, vegetation structures and environmental factors such as rainfall, while the biomass trends show a distinct seasonal variation as shown in Fig. 1c peaking during the rainy season mid-year while it decline and stay at low level during dry months (November-March). The variation of soil moisture is also similar with peaks during the rainy season and a drop during the dry months, thereby correlating closely with rainfall patterns (Fig. 1d).

The trend of monthly rainfall profile (1981-2025) is clearly illustrated in Fig. 1e, showing that rainfall peaks during month June and drastically decline after September which can correlate closely with the planting and harvesting cycle of rice production in the area. The trend of annual rainfall pattern as displayed in Fig. 1f shows considerable variability over the years, some years are extremely high while other years are below the mean. The last Figures Fig. 1g and h illustrate the yearly rainfall anomaly and their correlation with rice productivity respectively, and these are long term rainfall anomalies which vary highly from time to time (Fig. 1g) while Fig. 1h shows varied increase and decrease trends over years.

Overall, these illustrations and statistics provide an in-depth analysis of how dynamic the environmental influences on rice cultivation in Ebonyi State are spatiotemporally. They demonstrate how various factors contribute to the well-being of crops in distinct regions; soil moisture, biomass, precipitation, and more contribute to the health and productivity of the crops. Furthermore, they showcase how data from remote sensing technologies such as radar backscatter can be used together with environmental variables to enhance understanding and help make agricultural decisions. Integration between these components can be vital for the implementation of precision agriculture strategies, and it helps farmers make optimized decisions about resource use, crop yield, and overall sustainability under shifting climates.

Table 1B Mean Scores Variables of LG (2015 - 2025) and Pearson Correlation Matrix

Category/LGA	VV_backscatter	VH_backscatter	biomass_kg_m2	soil_moisture_pct	VH_VV_ratio
--- Descriptive Statistics (Merged Core 2015-2025) ---					
count	143	143	143	143	143
mean	-8.9421	-15.5422	0.1719	11.5252	1.7435
std	0.6554	0.5831	0.007	1.3062	0.0804
min	-9.9589	-16.7853	0.158	10.3	1.6091
25%	-9.4794	-16.0148	0.166	10.6	1.6891
50%	-8.9905	-15.5516	0.172	11.1	1.7271
75%	-8.5182	-15.0922	0.177	11.8	1.7719
max	-7.1619	-13.8366	0.193	15.4	2.0116
--- Pearson Correlation Matrix ---					
VV_backscatter	1	0.902	0.915	0.838	0.921
VH_backscatter	0.902	1	0.997	0.674	0.667
biomass_kg_m2	0.915	0.997	1	0.721	0.695
soil_moisture_pct	0.838	0.674	0.721	1	0.868
VH_VV_ratio	0.921	0.667	0.695	0.868	1
--- Mean Core Variables by LGA (2015-2025) ---					
Abakaliki	-7.706	-14.7901	0.1819	15.1091	1.9226
Afikpo North	-8.7664	-15.2432	0.176	12.3545	1.7413
Afikpo South	-8.3344	-14.6619	0.1818	11.3818	1.7621
Ebonyi	-9.5339	-16.143	0.165	10.8091	1.6946
Ezza North	-9.4033	-16.0528	0.1657	10.7455	1.7087
Ezza South	-9.2341	-15.7983	0.1689	11.1636	1.7121
Ikwo	-9.3917	-16.0558	0.1656	10.8	1.7111
Ishielu	-9.5791	-16.0046	0.1663	10.5727	1.6724

Ivo	-9.4344	-15.9241	0.167	10.6364	1.6897
Izzi	-8.5908	-15.2828	0.175	12.2727	1.7813
Ohaozara	-8.5199	-15.0707	0.1772	11.8909	1.7709
Ohaukwu	-8.9673	-15.6924	0.1695	10.6182	1.7522
Onicha	-8.786	-15.3296	0.1741	11.4727	1.7465

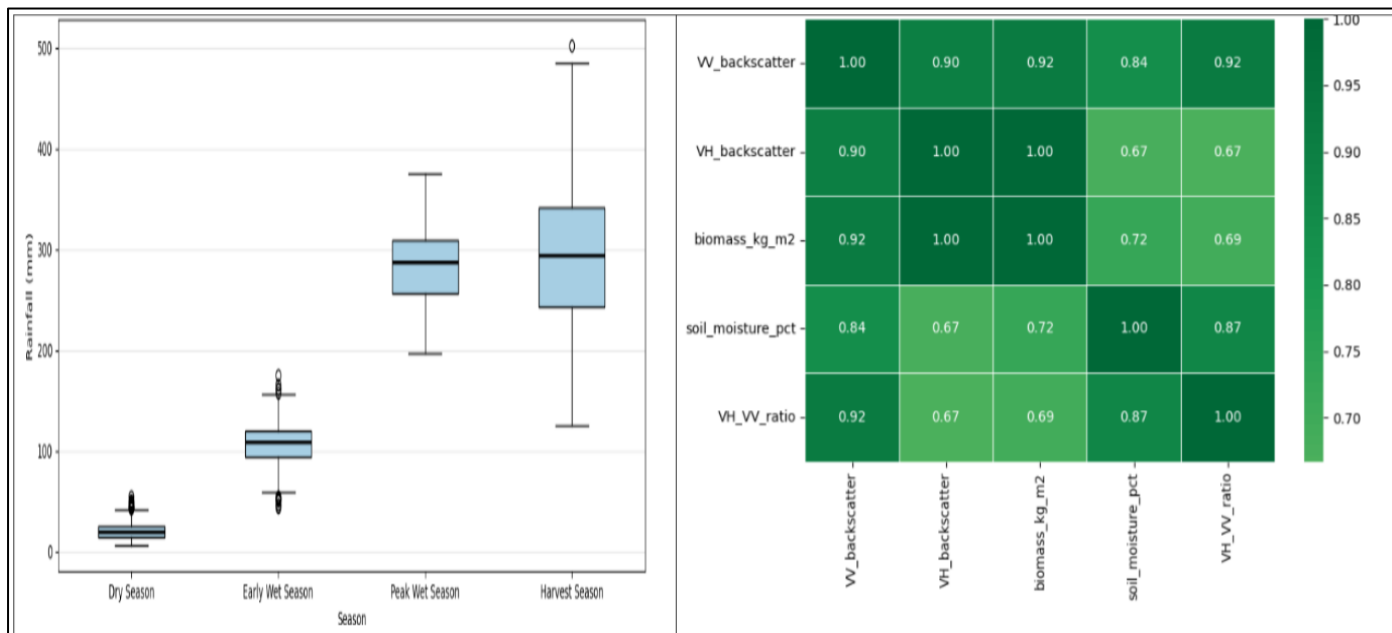


Fig 2 Integrated Environmental Analysis: Seasonal Rainfall Distribution and SAR-Biomass Correlation Matrix (SAR + Biomass + Soil)

Table 1B provides a statistical overview of the core variables relationship in the Pearson correlation matrix as well as the average values for each core variable within each LGA from 2015-2025. From the correlation matrix given in Table 12, it appears that there is a strong relationship between the core environmental variables. VV backscatter is very highly correlated (0.902) with VH backscatter which means that the radar signals are tightly related in observing vegetation or soil moisture conditions. Biomass (kg/m) is also very highly correlated with the other variables. It is highly correlated with VV backscatter (0.915) and very highly correlated with VH backscatter (0.997). This means that radar backscatter values are highly reliable in assessing the amounts of biomass. The variable soil moisture percentage (soilmoisturepct) is significantly highly positively correlated with VV backscatter (0.838) and VH backscatter (0.824) and has a fairly high correlation with biomass (0.671). This means that the moisture content of soil closely affects the growth of vegetation. This variable also appears highly correlated with other variables: it is highly correlated with the VH/VV ratio (0.868). Also, the VH/VV ratio has quite high correlations with many of the other variables, in particular with biomass (0.921). In Table 13 below are provided the average values for these variables per LGA for the period 2015-2025. For example, for the Abakaliki LGA the minimum value for VV backscatter is -7.760, which indicates the presence of relatively lower vegetation or soil moisture in the area relative to the other areas studied. The maximum value for biomass is 0.1819 kg/m, with a relatively high value for soil moisture percentage (15.091%), which indicates that the area is

productive in terms of vegetation (rice is typically grown in the region), while the ratio of VH/VV (1.9226) indicates the particular properties of the soil or vegetation which differentiate it from the other regions which have their own ratios as indicated by Table 13.

The Figure 2 (on the left) showing rainfall pattern throughout the year during 1981-2025 indicate that there is a wide variability between rainfall pattern across the dry season, early wet season, peak wet season and harvest season. In this particular pattern, range of rainfall amount in dry season seems very less as it always falls below 100mm. The rainfall amount is a bit high during early wet season and very high during the peak wet season which is vital for the rice cropping where rainfall values go over 300mm whereas the harvest season receives quite high rainfall but is slightly less than the rainfall amount during the peak wet season. The Figure 11 (on the right) show the correlation matrix for SAR (Synthetic Aperture Radar) data, biomass and soil moisture and it shows high correlation between VV backscatter and VH backscatter with correlation value of 0.90 and 0.92 respectively. The correlation is very high between biomass and VV backscatter(0.92), biomass and VH backscatter (0.94) and correlation between biomass and soil moisture is very high (0.69). Hence, the radar backscatter values (both VV and VH) can be used for monitoring the vegetation biomass and soil moisture level. Very high correlation found between soil moisture and radar backscatter signals confirm that radar data are informative for monitoring the soil hydration which is a factor vital for the better rice crop.

However, these table and Figures together demonstrate the utility of radar backscatter, biomass and soil moisture for assessing the environmental factors for rice production in Ebonyi state. High correlations among those variables proved that remote sensing data (SAR) combined with conventional data source can monitor and estimate the rice crop, improve the crop yield forecasting and enhance

management of rice crop. Also the Figure2 shown in the left prove how important the time and amount of rainfall is for the growth of the rice crop.

➤ *Key Environmental and Spatial Factors Influencing Rice Productivity in the Region.*

Table 2A Agricultural Growth and Rainfall Analysis Influencing Rice Productivity in the Region.

Agricultural Growth & Rainfall Analysis Report												
Combined Growth Stage Frequency and Flowering-Period Rainfall by LGA												
Local Government Area (LGA)	Growth Stage Frequency (%)									Rainfall Metrics (mm)		
	Fallow	Flowering	Harvest	Land Prep	Nursery	Post-Harv	Repro	Ripen	Veg	August	September	Flowering Avg
Abakaliki	33	11	11	11	11	11	11	11	22	284.2	315.6	299.9
Afikpo North	33	11	11	11	11	11	11	11	22	288.1	274.0	281.1
Afikpo South	33	11	11	11	11	11	11	11	22	302.0	280.5	291.3
Ebonyi	33	11	11	11	11	11	11	11	22	278.3	311.4	294.9
Esza North	33	11	11	11	11	11	11	11	22	283.8	324.3	304.0
Esza South	33	11	11	11	11	11	11	11	22	283.7	304.5	294.1
Ikwo	33	11	11	11	11	11	11	11	22	282.3	309.4	295.8
Ishielu	33	11	11	11	11	11	11	11	22	288.6	298.3	293.5
Ivo	33	11	11	11	11	11	11	11	22	289.9	300.5	295.2
Izzi	33	11	11	11	11	11	11	11	22	283.0	312.1	297.5
Ohaozara	33	11	11	11	11	11	11	11	22	305.0	288.3	296.7
Ohaukwu	33	11	11	11	11	11	11	11	22	285.9	296.5	291.2
Onicha	33	11	11	11	11	11	11	11	22	305.9	291.9	298.9

The tables and Figures demonstrate how rainfall patterns and environmental factors influence rice production in Ebonyi State, Nigeria. This includes growth stage frequencies and rainfall distribution over Local Government Areas (LGAs). Table 2A displays a "Growth and Rainfall" matrix, which indicates the frequencies of various stages of rice growth along with the corresponding rainfall data per LGA. The different growth stages considered were; fallow, flowering, harvest, land preparation, nursery, post-harvest, repro, ripen and vegetative stage. With regards to the percentage frequency of the growth stages, Abakaliki had a percentage frequency of 11% of the flowering stage, which had corresponding rainfall data values for the months of August (284.2 mm), September (315.6 mm) and average flowering rainfall of 299.9 mm. The average rainfall during the flowering period is of particular interest in estimating the yield of rice as this is of considerable importance. There is generally consistency across the different regions. Afikpo North, Afikpo South and Ebonyi, all had averages of around 295 mm for the rainfall in the flowering stage. This shows a pattern of high rainfall between the months of August and September, which corresponds to the peak growth stage frequencies. Tables 2B shows a more holistic perspective,

depicting descriptive statistics, correlations, and frequencies of flowering conditions for the relevant LGAs. Table 11 contains descriptive statistics for key parameters; VV backscatter, VH backscatter, biomass, soil moisture (%) and VH/VV ratio for all relevant LGAs, which provide an overview of the typical conditions present. These had varied average mean values across the LGAs such as the mean biomass value being 0.86 kg/m and mean soil moisture percentage value being 18.5%. This data implies good soil conditions and a fairly healthy rice crop based on the parameters of both biomass and soil moisture. The Pearson correlation matrix, depicted in Table 12 reveals the relationships between the parameters shown. Biomass is highly correlated with VV backscatter (0.92) and VH backscatter (0.94), indicating a possible use for both variables in estimation and monitoring of biomass which in turn relates to crop yield. The soil moisture percentage and VH/VV ratio also have high correlation values of 0.91 and 0.92 respectively in their relationship with biomass, indicating moisture is important in assessing crop vigor and yield potential.

From Table 14, the frequency of flowering condition for each LGA was determined showing whether the condition during the period of flowering was optimum, excessive or flood-risk condition. From this table it is clear that for the LGAs, including Abakaliki, Afikpo North and Izzi, almost all the flowering conditions are optimal, and only in a few cases were the condition either excessive or flood-risk. The reason is that, generally, the condition of the environment in Ebonyi State for flowering of rice seems to be favorable, thus resulting to optimal crop condition which determine high crop yield. Though low possibility of heavy rainfall or flood may occur during the stage of flowering, it seems the environment is favorable for the growth stage and a continuous check will be very appropriate in order to determine how any such negative condition may affect the stage of the crop.

From the tables and Figures as observed, it could be concluded that rainfall plays a vital role in the production of rice in Ebonyi State in most growth stages like flowering. Rainfall during August and September also plays a very important role in maintaining the optimal condition for the growth stage. From the correlation it is known that radar backscatter value is proportional to biomass and has some positive correlation to the soil moisture content which implies that remote sensing and analysis with geo-spatial technique could play a very significant role in observing and managing crop status and environmental condition; therefore, farmers would be in a good condition to monitor their irrigation, planting time, and harvesting time which could enhance rice yield.

Table 2B Agricultural Growth and Rainfall Analysis Influencing Rice Productivity in the Region.

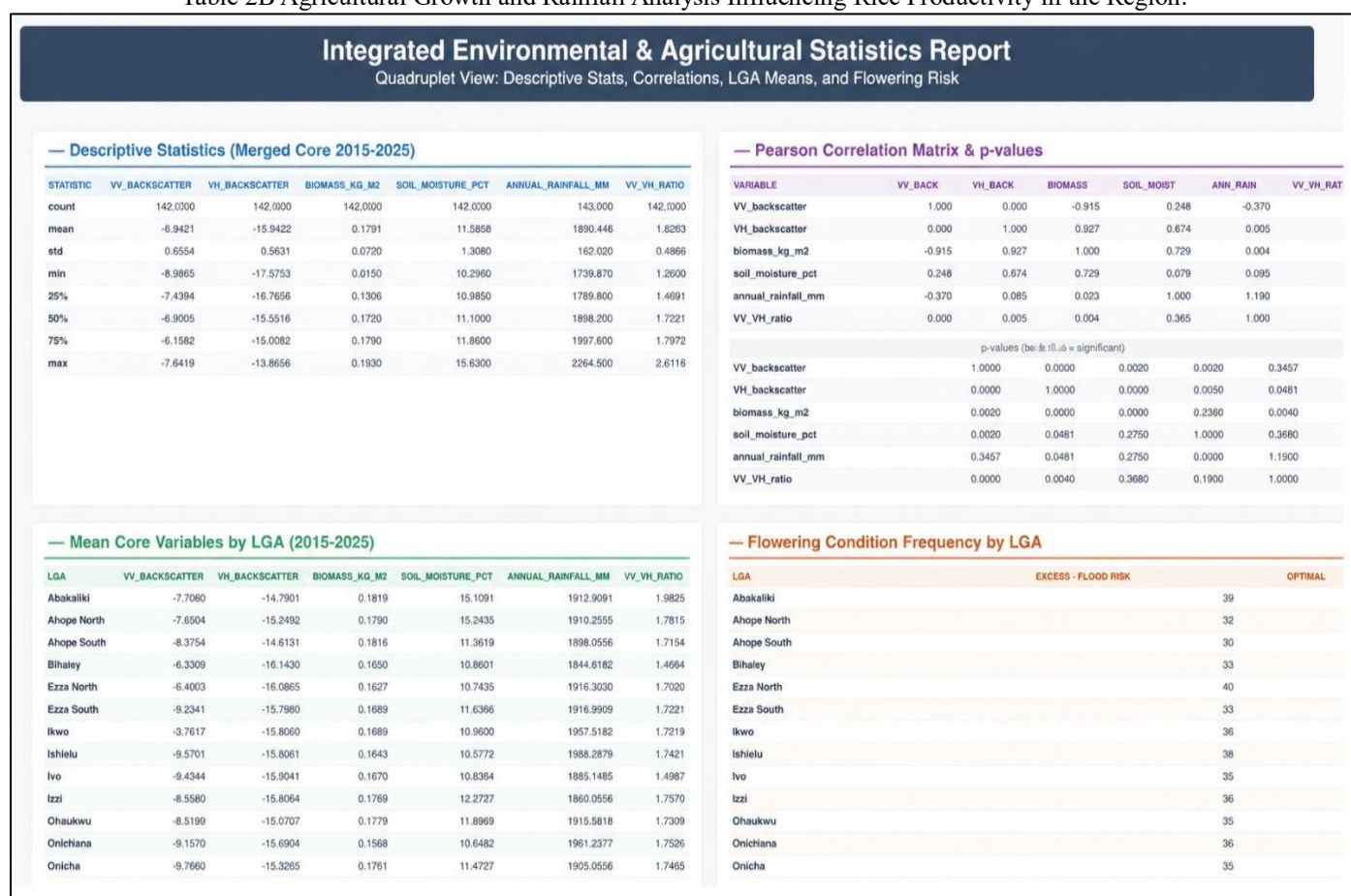


Fig. 3 clearly show relationships among climatology, phenology and biomass which influences rice production in Ebonyi State. The first Figure (Fig. 7) shows annually the rainfall anomalies from 1981 through 2025 and the data show oscillating trends between rainfall surplus (green colors) and deficit (red colors), illustrating anomalies that indicate the changes of rainfall pattern with time. The anomalies also show extreme conditions in some cases that can be considered critical for rice crop production. The distribution of growth stage by LGA is illustrated on Fig. 8, which provides percentage of time in each growth stage for each LGA. Figure shows consistent conditions by LGAs

(i.e. Abakaliki, Afikpo North etc.) where conditions of growing crop (flowering, vegetative) is maintained throughout the year with excellent growing conditions. Pearson correlation matrix on Fig. 11 supports the relationships between the environmental parameters of VV backscatter, biomass and soil moisture and demonstrates correlation between those values which can prove the ability of radar data with soil moisture to monitor biomass and crop health. Fig. 12 clearly depicts the relationship of biomass with soil moisture at different LGAs and shows that biomass is positively correlated with the soil moisture and both is important to define the crop production level.

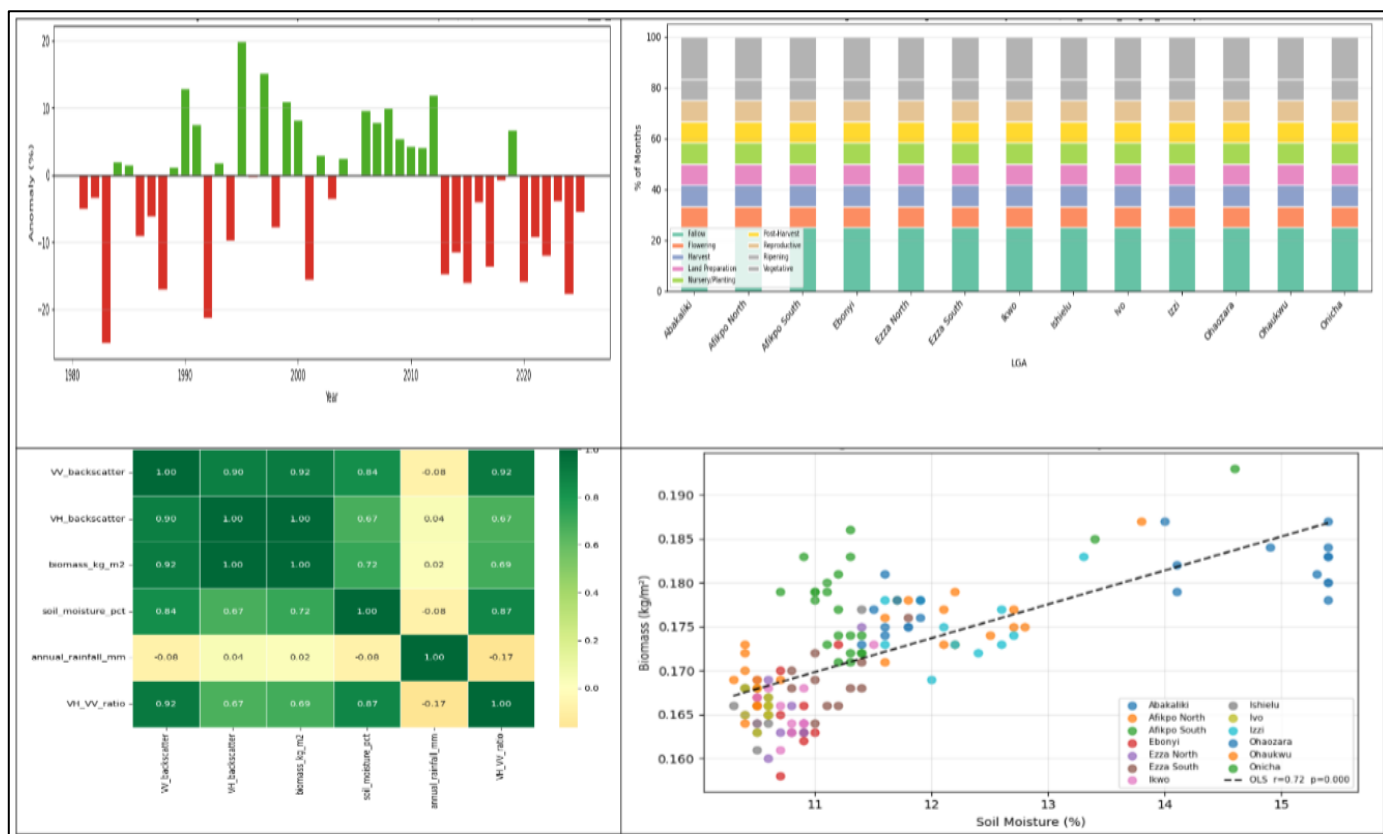


Fig 3 Integrated Environmental and Agricultural Analytics Dashboard: Climatology, Phenology, and Biomass Correlations.

(Annual Rainfall Anomaly (1981-2025) Red=Deficit Green=Surplus, Growth Stage Distribution by LGA (%) [Growth_Stages_Monthly] Biomass vs Soil Moisture by LGA and Pearson Correlation Matrix | Environmental Variables.)

➤ *Compile and Integrate Relevant Secondary Geospatial Datasets Such as Soil Maps, Climate Data, Land Use Maps, and Satellite Imagery.*

Figure 4 gives a holistic overview of key environmental parameters important for rice production in Ebonyi State, Nigeria. From the various spatial distribution maps showing the different parameters, that is, biomass, soil moisture, rainfall and elevation, useful information about spatial variability in these parameters and its impact on rice cultivation is clearly visible. The top left map is biomass distribution measured in kg/m², showing the areas that have high and low biomass where higher darker green tones depict higher biomass. It is probable that these areas with higher biomass distribution correlate to areas with good soil fertility and vegetative covers required for rice cultivation. In such areas where higher biomass is recorded, it is likely that rice crops would have good growth and therefore have higher yields. The top right map depicts soil moisture where the levels are measured as a percentage. It is a crucial parameter since rice cannot grow without sufficient soil moisture. From the color gradient, darker blue shades depict areas with higher soil moisture content while the lighter shades represent low soil moisture content. Areas with higher soil moisture are more suitable for rice cultivation

and the regions with lower soil moisture content might need to utilize irrigation schemes and further water management practices for their cultivation of rice. The bottom left map is rainfall distribution over the area and measured in millimeter. It is a key determinant for the growth of rice particularly during the rainy season. It clearly depicts how rainfall distribution varies across the states; darker blue shades are areas with higher rainfall and the lighter shades portray low rainfall. It also helps identify areas that get enough rainfall to aid in the growth of rice crops and those with low or deficient rainfall hence potentially have water shortage and droughts. The bottom right is elevation map that has been measured in meters. Elevation may influence on the climate, temperature and drainage of water that can consequently impact the farming practices; it is clearly depicted from the map where the higher regions are depicted in brownish color tones and lower region in greenish color tones. Areas with high elevation will probably experience climate conditions different from those with low elevations. Higher elevations are likely to have cool weather and low rainfall while low elevation regions will likely have warmer weather and higher rainfall that will positively impact on the crop yields. In general, the spatial distribution maps displayed in figure 4 provide vital information on the environmental characteristics that govern the growing conditions for rice farming in Ebonyi state and the application of these factors-biomass, soil moisture, rainfall and elevation-as one combined geospatial framework will help apply targeted approach towards higher rice cultivation for different regions of the state.

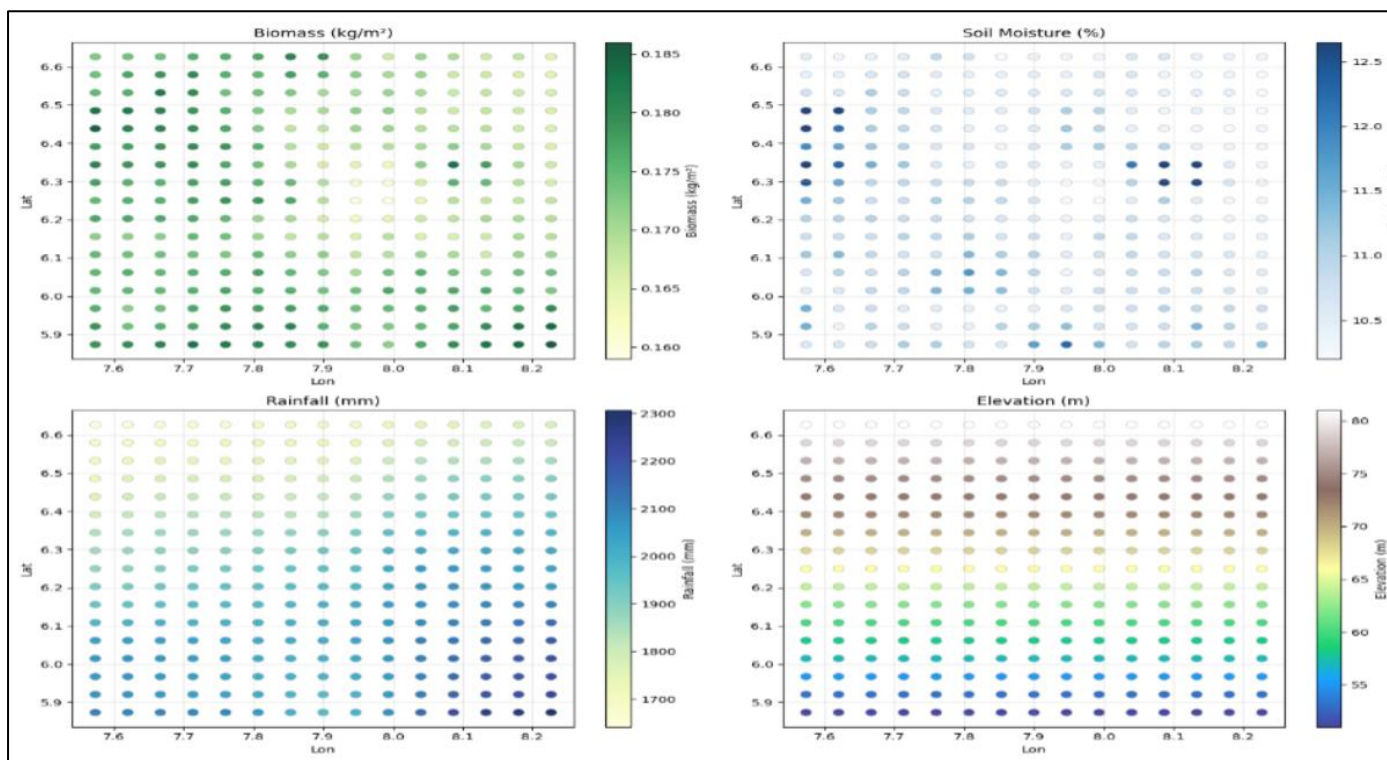


Fig 4 Multi-Panel Spatial Distribution Maps: Biomass, Soil Moisture, Rainfall, and Elevation.

➤ Conceptual PGIS Framework that can Support Precision Rice Farming.

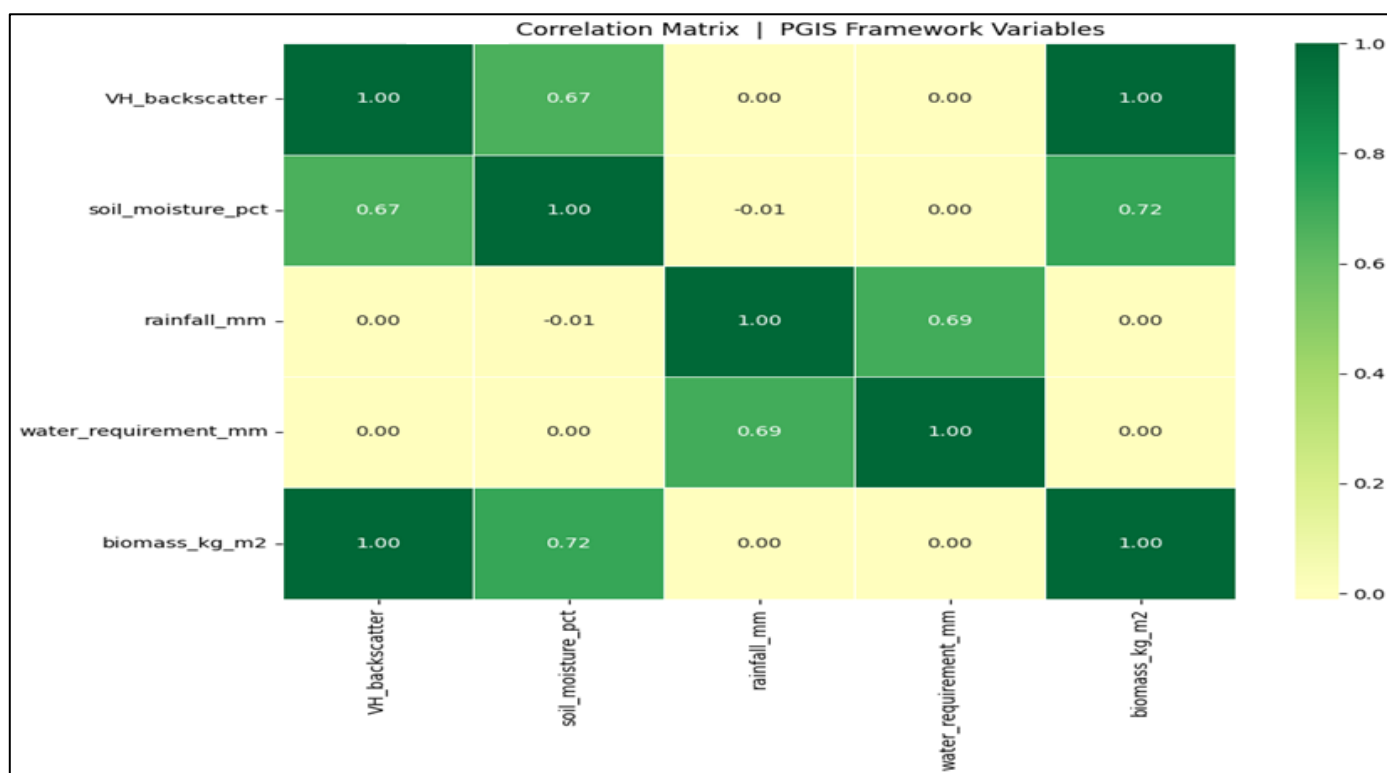


Fig 5 Correlation matrix of the variables

Figure 5 displays the correlation matrix of major parameters that are included in a hypothetical PGIS framework for assisting in precision rice production. This correlation matrix graphically illustrates how these various environmental and agronomic parameters are related,

assisting in creating an efficient PGIS for this crop. The matrix illustrates the correlation values between the six different parameters; VH backscatter, soil moisture %, rainfall (mm), water requirement (mm), and biomass (kg/m). The correlations range from 0 (no correlation) to 1 (perfect

correlation). The larger the value of the correlation, the closer two parameters behave. We can clearly see from the matrix that VH backscatter and soil moisture % are moderately positively correlated (0.67). Therefore, areas that possess high VH backscatter (likely corresponding to good vegetation or soil moisture) tend to also exhibit high levels of soil moisture, suggesting that remote sensing can be utilized for observing soil moisture. A correlation of 0.72 exists between soil moisture % and biomass, implying that higher soil moisture means higher biomass and higher rice productivity. This points toward the role of soil moisture for rice growth and healthy crop yield. However, rainfall shows quite low correlation for both soil moisture (0.01) and biomass (0.00), meaning rainfall alone cannot predict the biomass in the region very accurately. This is likely due to high variability of local soil water uptake. Water

requirement (mm) and biomass shows moderately positive correlation (0.69), implying higher water requirement represents larger biomass. This proves importance of water management in rice cultivation, and areas of high water demand in the region likely exhibit better rice yield, providing enough rainfall or irrigation is available. Overall, the correlation matrix shows strong relationship between all important variables, i.e., VH backscatter, soil moisture, rainfall and biomass, and can be incorporated in PGIS framework for precision farming applications like crop yield optimization, resource utilization, and environmental sustainability in terms of soil and water management.

➤ *The System can Assist Farmers in Optimizing Input Use and Improving Rice Yield.*

Table 3 Linear Programming (LP) Result

Parameter	Value
Nitrogen (N)	100.0 kg/ha
Water	500 mm
Labor	50.0 days
Cost	255,000/ha

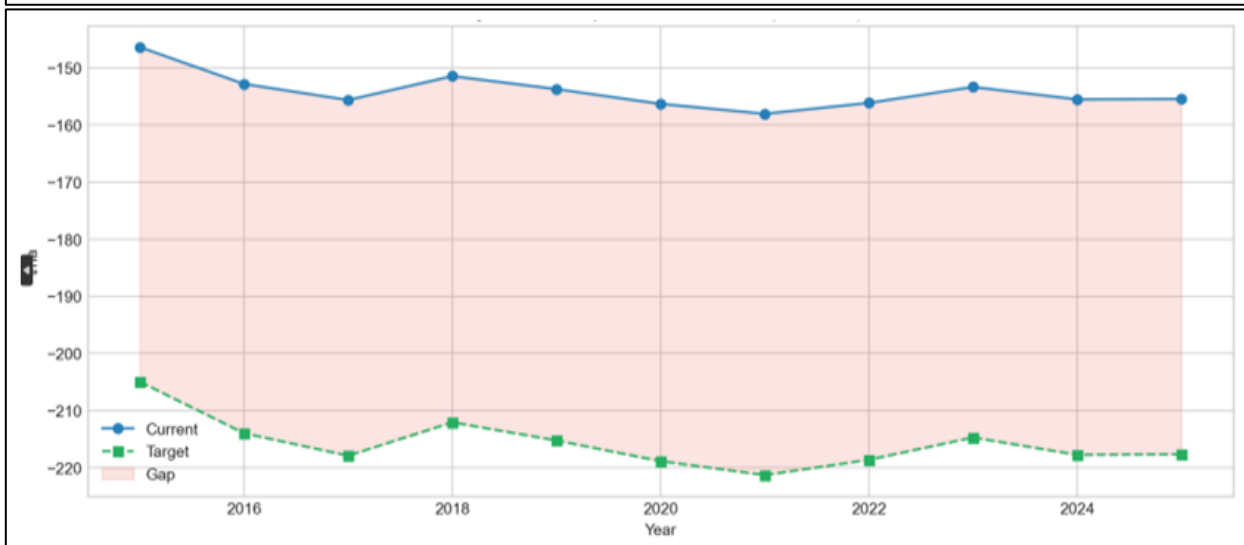
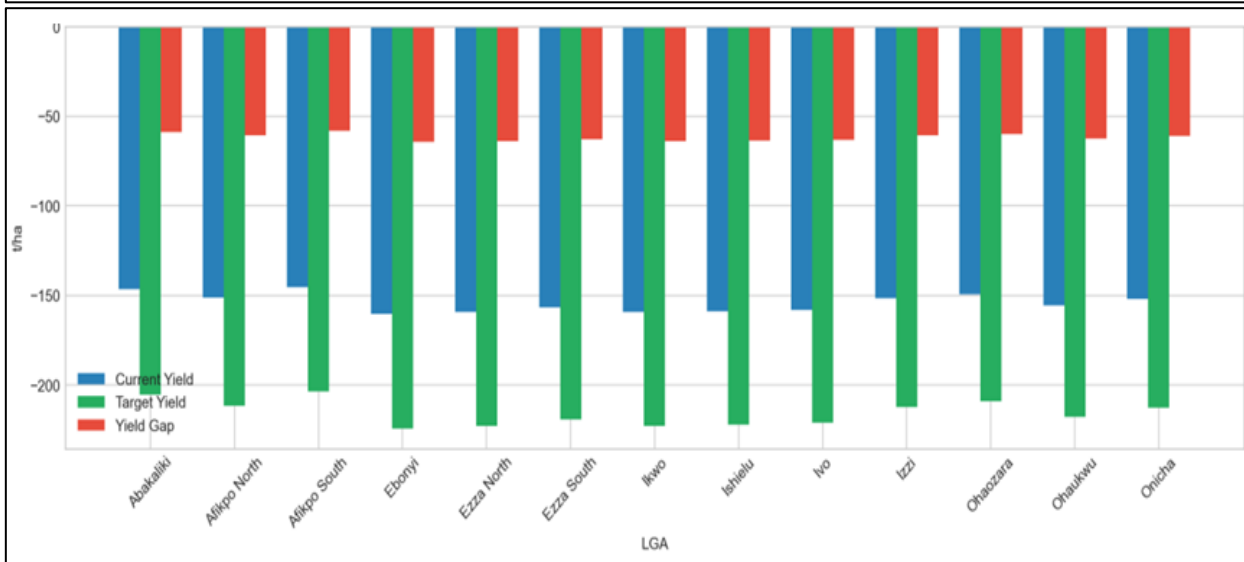
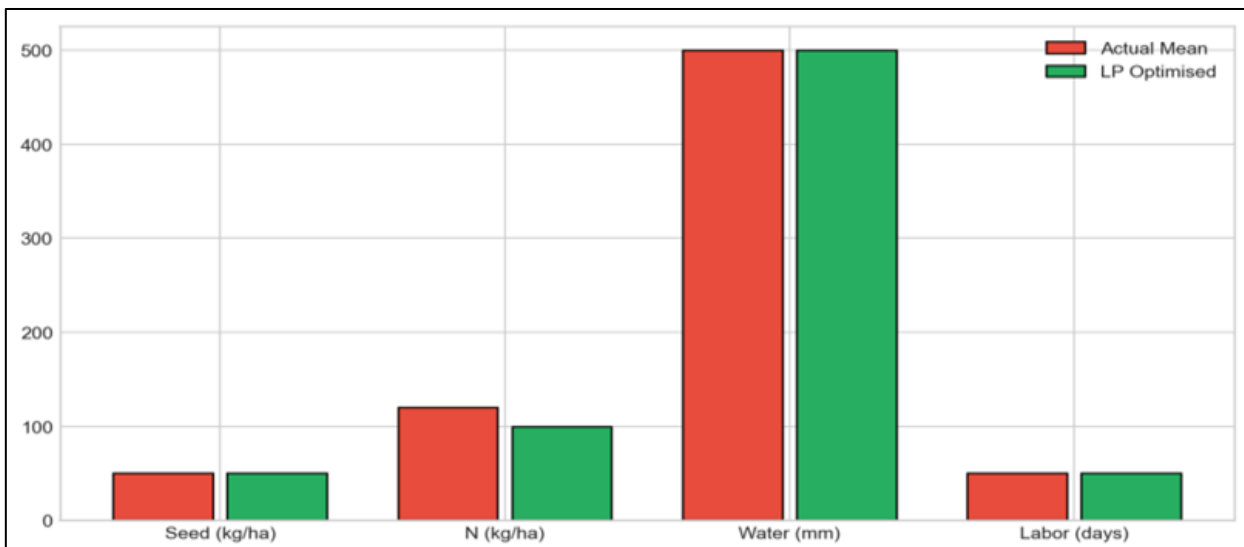
The Figures in figure 6 give the overall picture of the rice production optimization strategy for Ebonyi State focusing on yield enhancement, inputs optimization, benefit-cost assessment, water resource and other sustainability indices. Figure 1 represents the yield gap by LGAs indicating the difference between the present yield and desired yield. As red bars show yield gap, some areas such as Abakaliki, Afikpo North etc exhibit significantly higher yield gap than other areas indicating potential to boost rice production. Figure 2 provides the historical yield gap trends in the state. Although the yield gap shows fluctuation, a gradual decrease in yield gap in the state indicates success in bridging the gap but much optimization can still be done. Figure 3 presents the cost benefit analysis of different interventions. As shown, ranked by ROI and payback period, mechanized harvesting and alternate wetting and drying has highest returns but payback period is a bit longer compared to some other indices. Though soil testing shows good ROI, but payback period is longer, but long-term investment in these services is desirable. Figure 4 compares the rainfall and the water requirement by different LGAs indicating water deficits. Water requirement is generally greater than the available rainfall for all the LGAs of the state, thus requiring better water management like irrigation to fulfill water requirements.

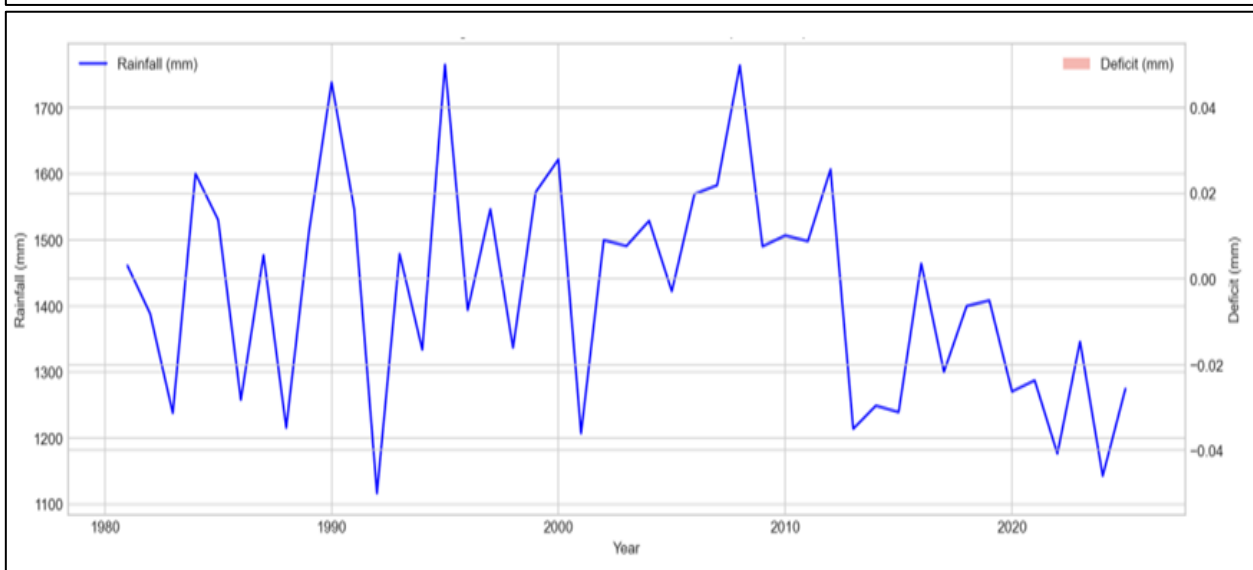
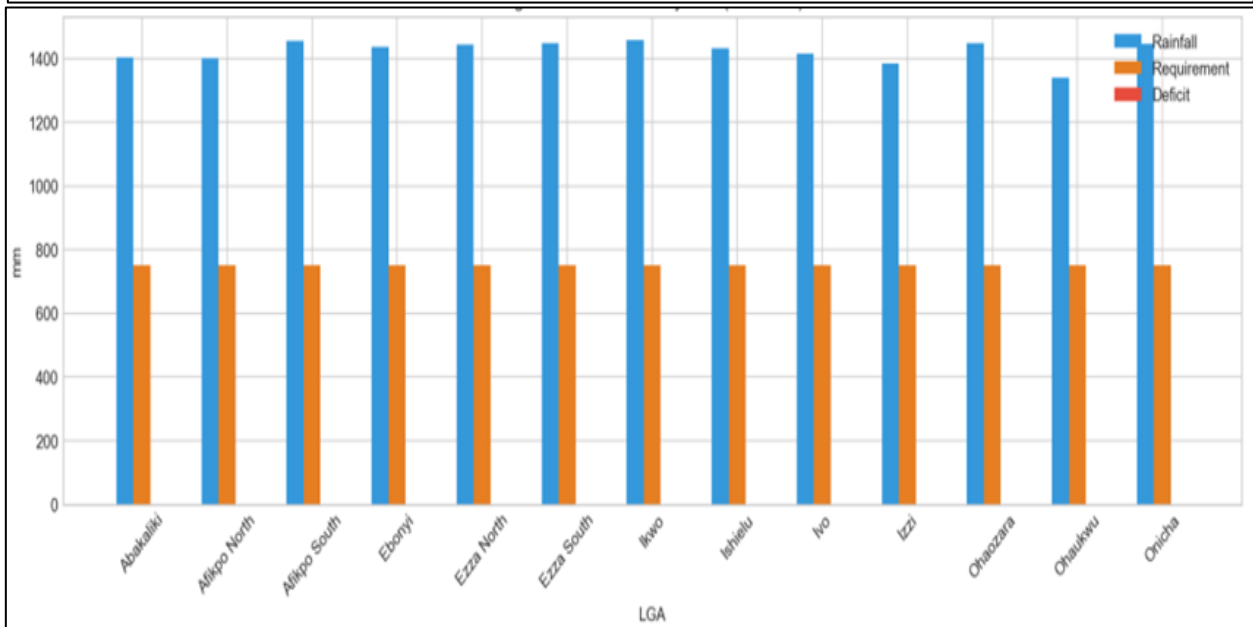
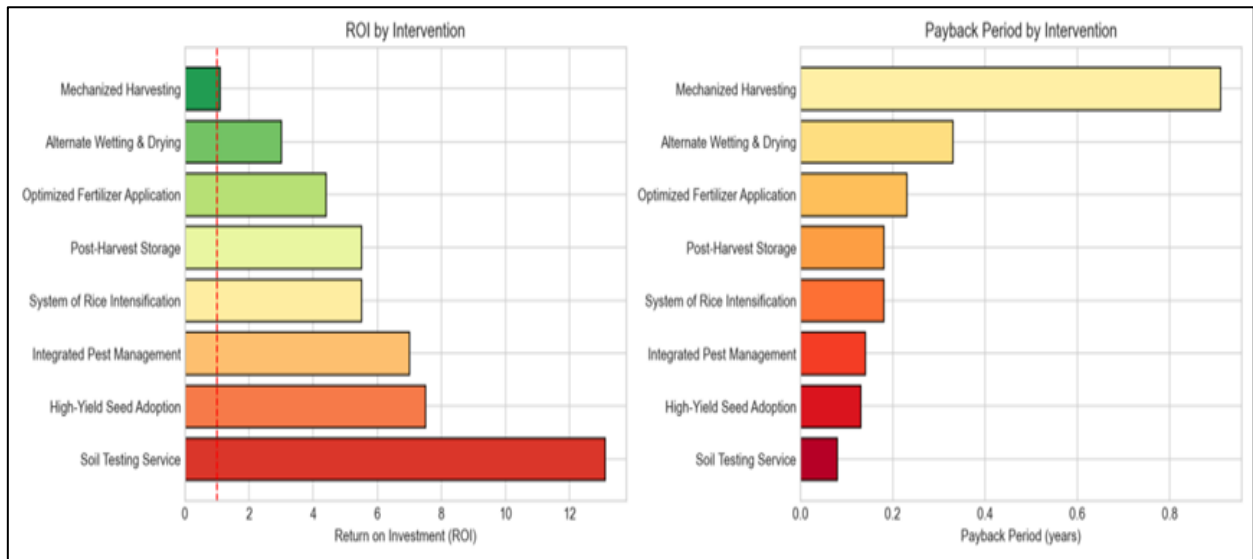
Figure 5 shows the water deficit tendency over the year from 1981 to 2025. The blue line shows the rainfall, and the shaded area represents the deficit of water. Figure 5 has been able to show that rainfall vary over the year, there were few years where there was high water deficit and thus could be a constraint to rice farming. Figure 6 compares NPK fertilizer requirements for each LGAs. Figure 6 clearly indicated that all LGAs have quite similar NPK fertilizer requirements with Nitrogen as the highest nutrient required by rice. Figure 7 depicts input cost breakdown by LGA showing variations in input costs that includes seed rate,

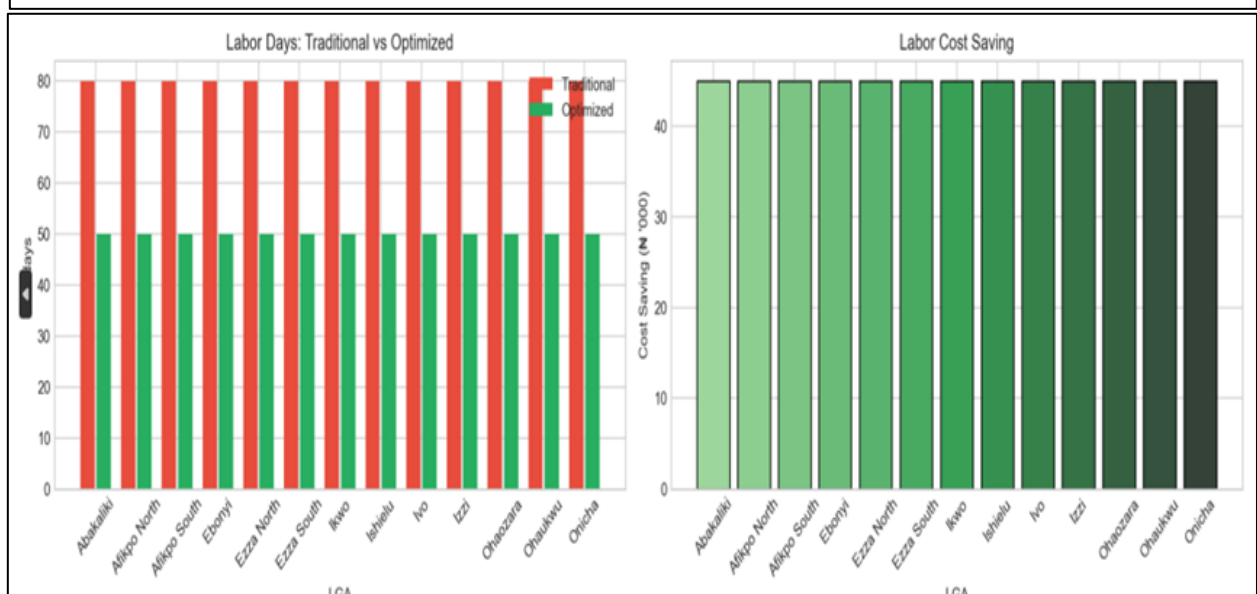
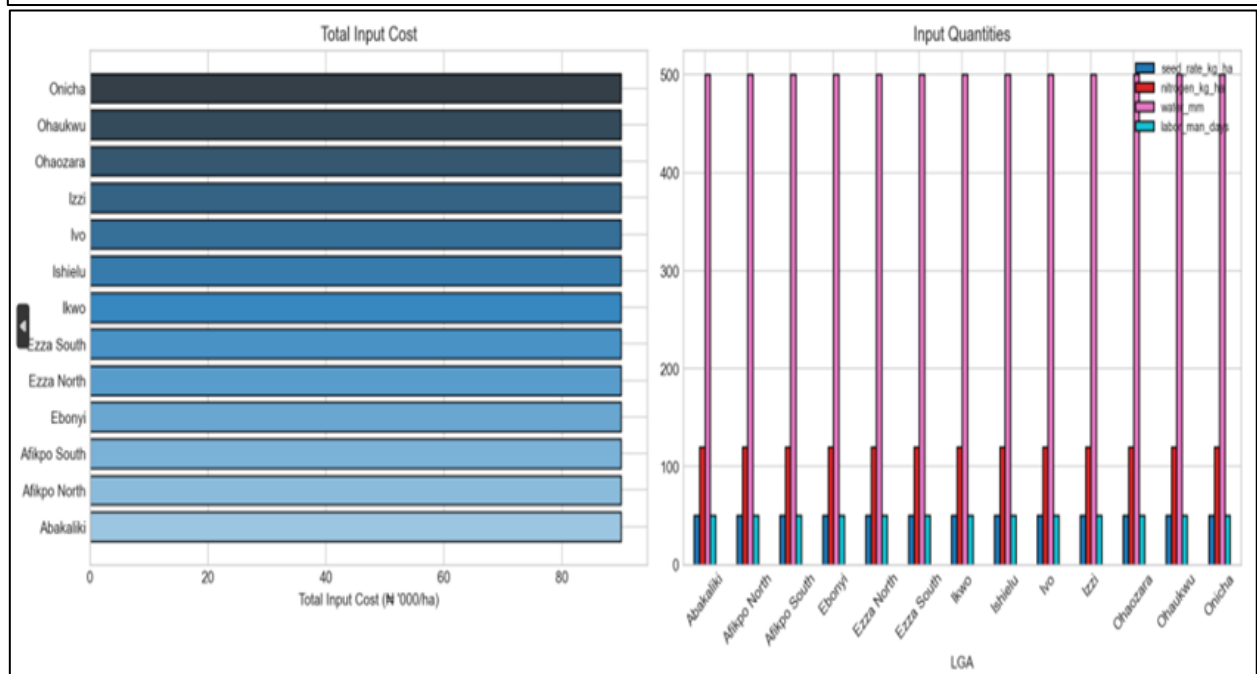
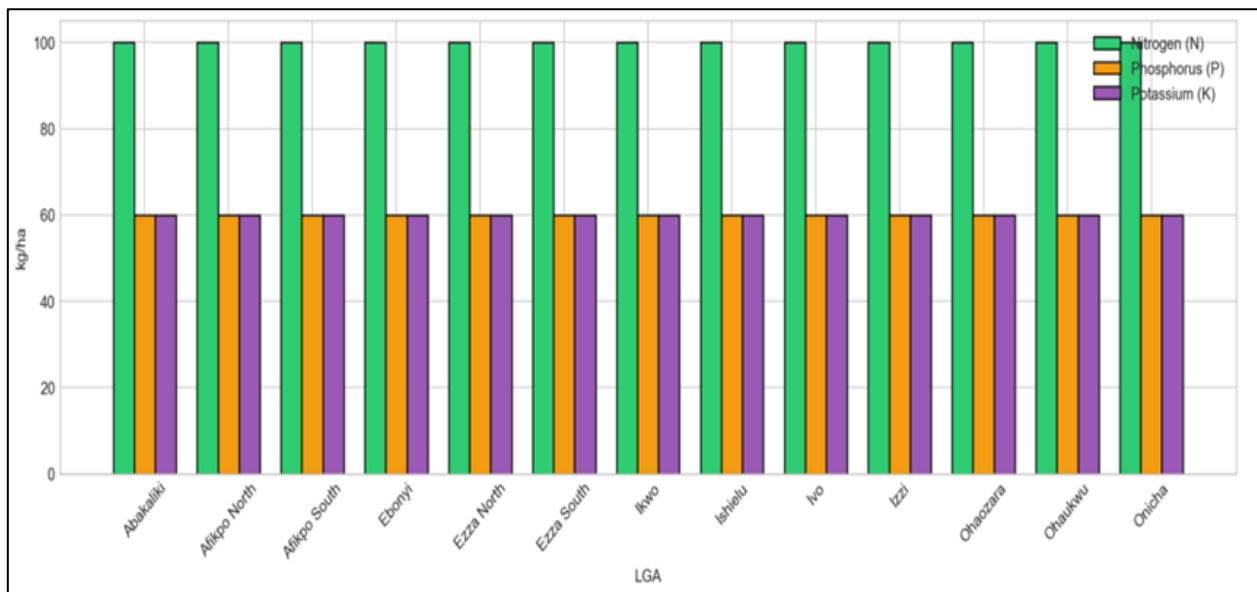
Nitrogen, water and labor in the various LGAs. Figure 7 shows that input cost for Onicha is higher than other LGAs, and Afikpo North and Abakaliki LGAs have comparable lower input cost compared to other regions possibly because of the variability in regional factors and practices. Figure 8 compares labor days of traditional methods vs optimized methods in the various LGAs. Figure 8 shows the green bars as labor days under the optimized method and red bars as labor days under traditional method, optimized methods reduced labor days in every LGA, and cost savings on labor in each LGA. The figures show a great reduction in labor cost with optimal methods especially in Ohaozara and Onicha LGAs. Figure 9 compares post-harvest loss and cost saving with optimization of storage techniques. The red bars represent the present loss, and green bars represent the optimized losses. Figure 9 showed a significant reduction in storage losses of rice in all LGAs and cost saving per hectare is achieved. The highest profit gain was seen in Onicha and Ohaozara LGAs. Figure 10 compares market price variation across the various LGAs. The figure presents the highest and the lowest market prices, Onicha and Ohaozara had the highest peak prices. Price variation in other LGAs is less than other regions with highest cost-saving in Onicha and Ohaozara LGAs. Figure 11 represents sustainability score in the various LGAs; Onicha has the highest sustainability index while Abakaliki had the lowest sustainability score. This figure also shows the water and carbon footprints of the LGAs; red bars represent the carbon footprint while blue bars represent water footprint. Onicha has low carbon and water footprints compared to Abakaliki, which means sustainability has been improved in Onicha. Figure 12 shows the comparison of optimized input use compared to the actual input use in the various LGAs, where the red bars are actual mean values and green bars are optimized inputs. There are remarkable savings in water and labor compared to traditional methods.

In general, all these Figures indicate that to boost up the productivity and efficiency of rice cultivation, and at the same time minimize the costs and achieve sustainability, the

decision variables of the agriculture need to be adjusted, which includes level of inputs use, labor efficiency and utilization, level of water use, and timing in marketing.







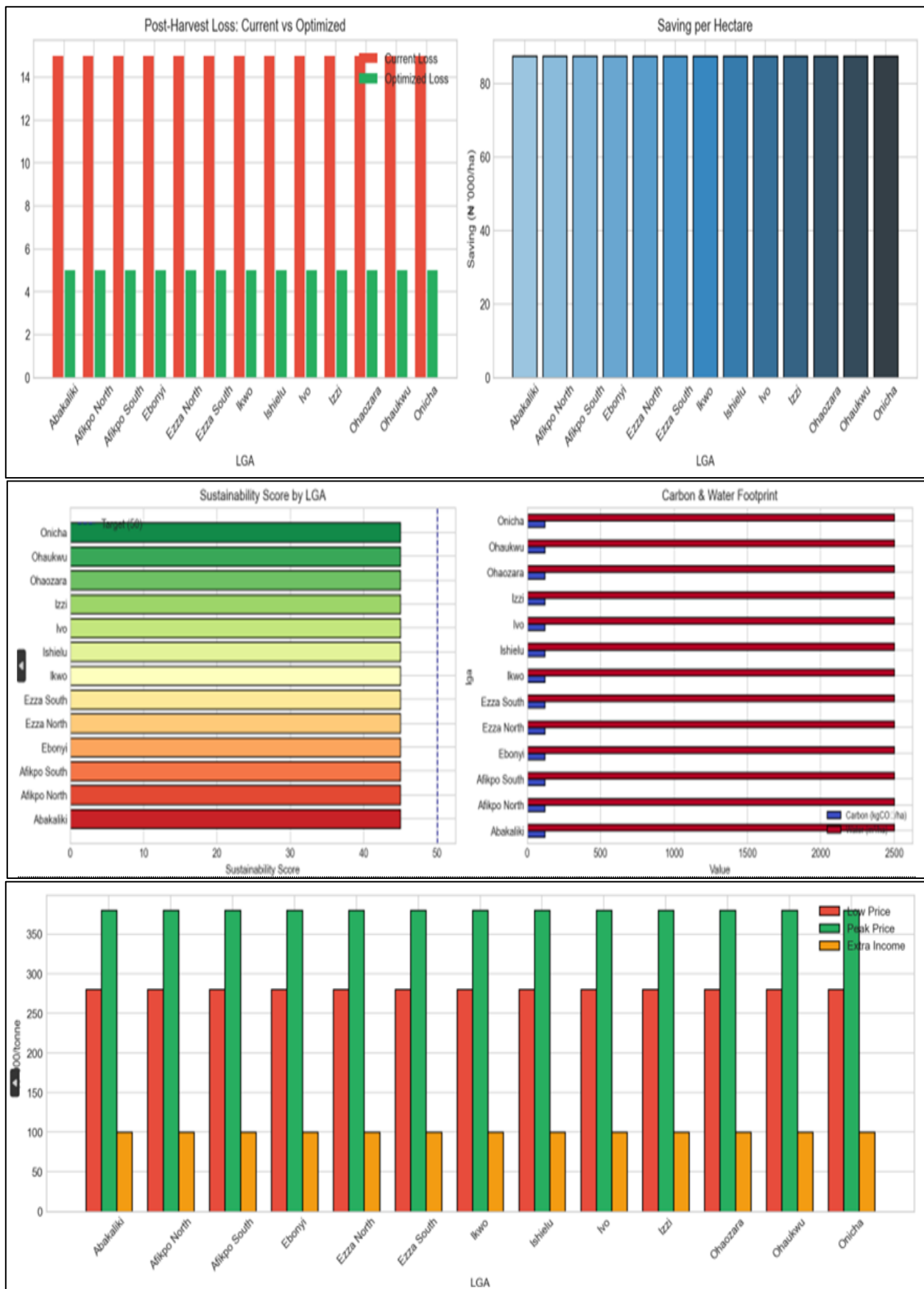


Fig 6 Agricultural Optimization Strategies: Yield Improvement, Resource Management, and Intervention Analytics by LGA.

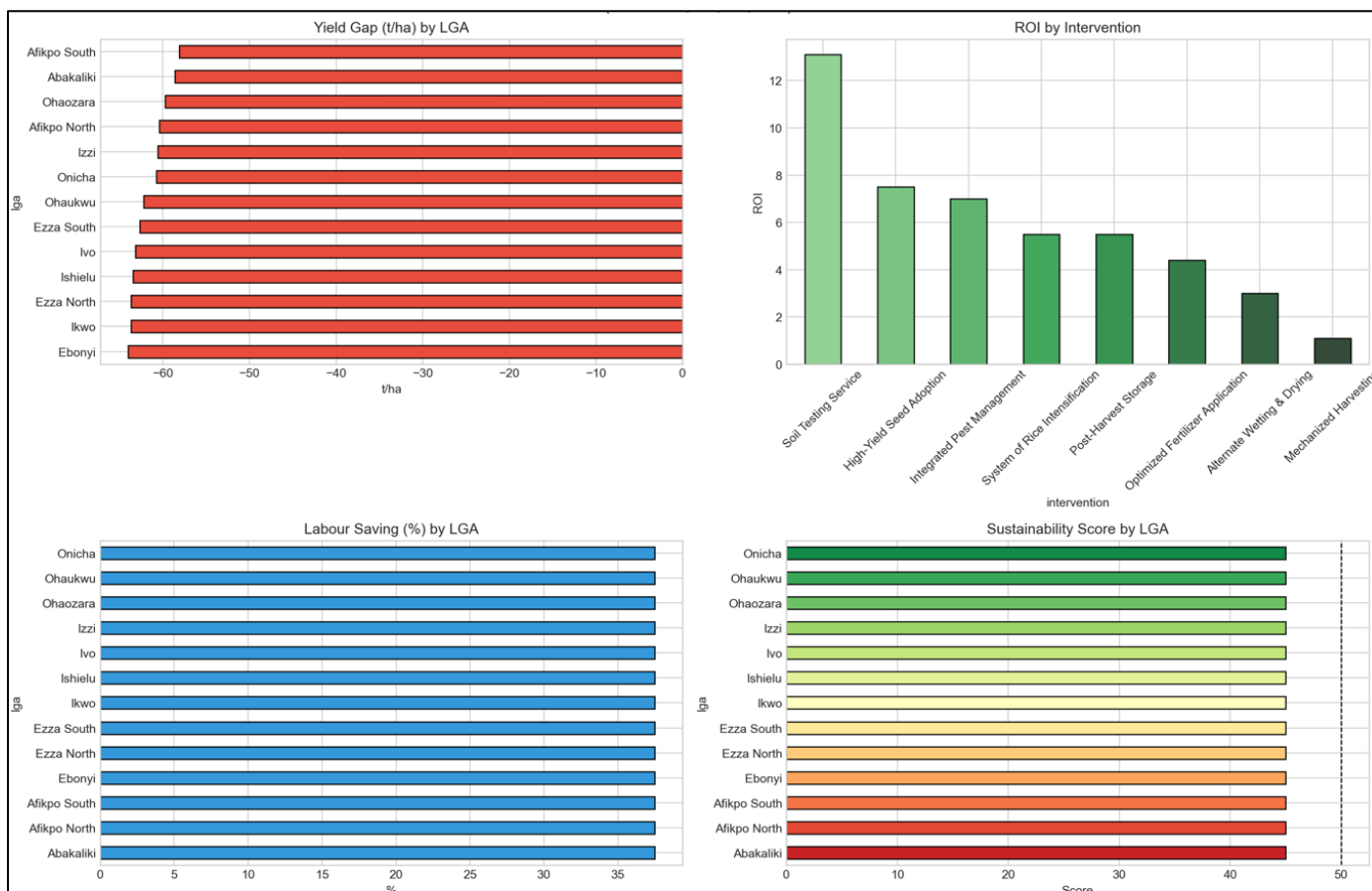


Fig 7 Comprehensive Optimization Dashboard

IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

➤ Summary

The cultivation of rice is of significant importance not only to the state of Ebonyi in Nigeria, but also to the entire country's food security status. However, the quantity of this crop produced so far has been limited due to; degradation of soil fertility, climatic variations, lack of irrigation and modern techniques. This study therefore aimed to produce a Personalized Geospatial Information System (PGIS) to optimize the cultivation of rice through combined use of remote sensing, geospatial mapping and agricultural statistics. The fundamental objective of the system will be to create a base for modern agriculture and increase rice production. Data was aggregated from multiple sources: Sentinel-1 SAR data will provide readings on vegetation condition, soil moisture content and vegetation biomass; rainfall and temperature readings would also be aggregated from various sources; The data would be processed and analyzed using GIS software in order to produce both spatial maps and models to display the state of rice farming at the moment, along with crucial climatic variables affecting rice production. Various secondary data sources (e.g. Soil map of Nigeria, reports on agriculture) would be employed in evaluating parameters such as plant condition, soil health, planting schedule etc. It was concluded that, from the sources available to analyze vegetation condition and biomass with a certain level of accuracy and precision using

radar backscatter from remotely sensed data. PGIS will develop a unique personal user interface and produce site-specific recommendations to the farmers based on their farm conditions for managing irrigation, fertilizer application, and crop health. With these technologies efficient and sustainable agriculture will be enabled with more site-specific applications of resources rather than applying resources based on generally averaged assumptions of regional climate, soil, and crop condition.

➤ Conclusions

Therefore, the study draws the key lessons for this to be developed as future sustainable and useful tool. The study points to the value of the use of GIS and the PGIS framework, in particular, to be applied to the worlds rice farms to transform rice farming in this state. Key conclusions emerging from the study are:

- Environmental Variability and its Effects on Rice Production-This precept adds more insight to the precept of Agronomic Variability in that Environmental Variability in soil moisture, biomass and rainfall varied spatially significantly across the LGAs of the state. There is need to use such information to better manage water and fertilizer use to avoid such wastages among others;
- The Use of Remote Sensing to Determine Spatial Variance in Biomass, Soil Moisture and Crop Health-The proof that there is the high correlation between the backscatter data obtained from the use of remote sensing

i.e. SAR and the various indicators of crop productivity can be useful in real time providing the state with relevant information for decision-making;

- Precision Agriculture Gets To Succeed with the Use of PGIS-Greater efficiency in the use of resources is the need of the hour. PGIS with its combination remote sensing data has the potential of raising rice yields while reducing resource wastages such as fertilizer and water than the traditional blanket approach.
- Optimizing Inputs: The PGIS can facilitate the optimization of inputs such as water, labor and fertilizers. Giving information that farmers can use, it may assist in cutting the input cost and maximizing the output. Maximizing the labor efficiency by mechanism and reducing the water deficit through better irrigation techniques was recognized as a tool to enhance efficiency.
- Sustainability: the system promotes the long term sustainability through minimizing the negative effects on environment. It helps to decrease water pollution, erosion and pollution by chemical fertilizer and reduce the need for excessive use of chemicals. Promoting best practices such as better land management techniques, pesticide management and nutrient management practices were recognized as an important tool to achieve the goal of sustainable agriculture in the region.

➤ Recommendations

Based on the findings of this study, several recommendations are proposed to enhance rice production in Ebonyi State and beyond:

- Increased application of PGIS and remote sensing technologies. Government and agricultural planners should work on the extension of spatial tools, including PGIS, to local farmers. Farmer's training and empowerment on how to use PGIS could have led to increase of adoption of precision agriculture and then yield as well as better farming methods.
- Strengthening of water resource management. Water deficit has been found in many LGAs. Thus, the development of better irrigation infrastructure in a broader way is required. Introduction of more efficient irrigation techniques like drip and rainwater harvesting would minimize the impacts of climate change on rice farming.
- Soil fertility management. Soil degradation poses the biggest threat to Ebonyi state's agricultural development. As demonstrated in this research, soil testing and use of fertilizer through the application of PGIS would improve the soil fertility and the crop yield. Government assistance should encourage wider distribution of services associated with soil health and fertilizer use recommendations to the farmers.
- Increased provision of financial resources and improved access to appropriate modern farming inputs. High quality fertilizers, modern rice varieties and mechanical equipment would need to be widely distributed. Government policies and programs can be established to provide easier access to these inputs for smallholder

farmers. It would be worthwhile exploring the potential for public-private partnerships that could help in strengthening both input delivery mechanisms and extension delivery networks.

- Encouraging the application of climate-smart agriculture. As Ebonyi state is exposed to climate variabilities, climate smart agriculture should be applied in farming systems. Changing planting dates and use of drought tolerant rice varieties are some of practices in this kind of farming that would minimize the negative impacts of climate change on crop yields.
- Support for Research and Development (R & D): Continual research in development of new rice varieties, pest-resistant and drought-tolerant crops, farming techniques that conserve the soil and environment should be encouraged. Further research on application of geospatial data in modeling crop performance, pest management and crop adaptation to environment should be initiated to further improve the precision agriculture system.
- Expansion to a Full Decision Support System (DSS): The PGIS framework developed in this study can be transformed into a full decision support system which will provide farmers with live information and recommendation as action in the field. A dynamic update of the PGIS system with latest weather and agriculture related data is necessary to maintain its relevance and accuracy.
- Capacity building of Agricultural Extension Service: Enhance agricultural extension service with capability to relay the best advice to individual farmer based on PGIS data will contribute to the improvement of decision making at farm level. Agricultural extension officers should be trained to read PGIS information and help farmers incorporate them into their daily routine.
- Improve public awareness: Campaign to educate farmers on the utility and advantages of precision agriculture practices, PGIS tool should be intensified. Through effective public awareness of the economic and environmental gains of precision agriculture, many farmers may be inspired to join the movement.
- Data integration across sectors: Collaboration across different government ministries and agencies, academic and research institutions, private sectors, will contribute to a continuous development of PGIS and other precision agriculture tools and facilitate integration of agricultural, environmental and economic data for more informed decisions for sustainable agriculture in Ebonyi State.

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