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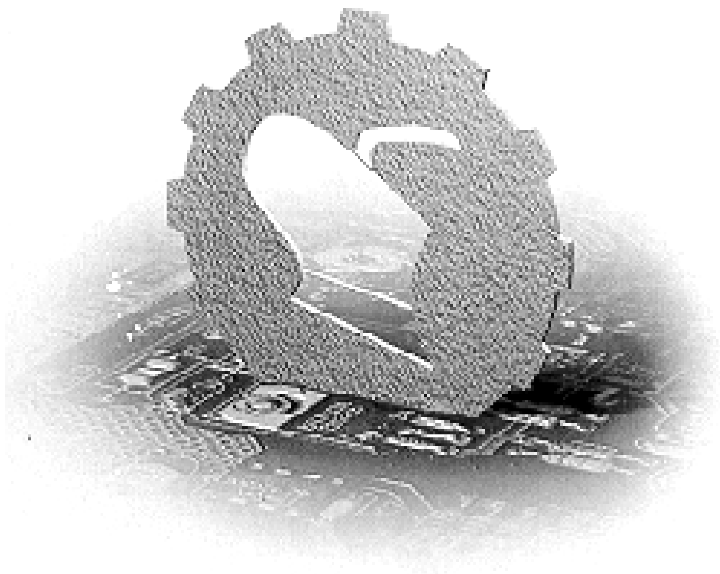

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INSTITUTE OF AGRICULTURAL ENGINEERING

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APPLICATION OF GLOBAL SATELLITE DATA AND MACHINE LEARNING MODELS FOR CROP CLASSIFICATION AND AGRO-ZONE IDENTIFICATION

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Abstarct: This study presents an applied approach to leveraging globally available satellite data—specifically the WorldCereal dataset—for the classification and spatial analysis of agricultural land. The dataset, developed under the European Space Agency (ESA), includes crop type, cropland probability, seasonality, and irrigation status for the year 2021, at 10-meter resolution. After filtering for high-confidence agricultural zones, we implemented Random Forest and XGBoost algorithms to classify crop types, and unsupervised K-means clustering to identify agro-zones with similar characteristics. Major crop categories included cereals, maize, rice, and pulses. The methodology was tested on a large subset of the global dataset, using a Python-based pipeline. Our results demonstrate that machine learning models can achieve high classification accuracy (F1 ≥ 0.98) even with limited input features, and that clustering techniques can reveal consistent spatial patterns without prior labeling. These findings highlight the potential of open-access satellite data and data-driven modeling in building cost-effective and scalable systems for precision agriculture, particularly in regions lacking detailed ground-truth information.

Keywords: *Remote sensing, land cover classification, tree-based learning algorithms, spatial data analysis, irrigation mapping, machine learning*

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INTRODUCTION

Agriculture today faces increasingly complex challenges, ranging from climate change and land degradation to the need for sustainable use of natural resources.

Within this context, numerous studies have positioned precision agriculture as a data-driven paradigm that integrates modern information and communication technologies (ICT) to enhance crop productivity, reduce environmental impact, and support sustainable resource management [11],[9],[8]. Key components of this paradigm include site-specific monitoring, variable-rate application of inputs, and real-time decision support systems. Remote sensing technologies, including satellite and UAV-based platforms, play a critical role by enabling timely and accurate mapping of field conditions at large spatial and temporal scales [9],[3],[4]. These capabilities provide essential inputs for optimizing seeding, fertilization, irrigation, and harvesting practices.

One notable initiative in this domain is WorldCereal, supported by the European Space Agency (ESA). This program aims to deliver global-scale datasets on crop types, cropland probability, seasonality, and irrigation by utilizing data from Sentinel-1 and Sentinel-2 missions. The resulting products are open-access, highly interoperable, and suitable for integration into diverse analytical systems [10].

Previous studies have shown that satellite data can successfully identify certain vegetation types. However, the application of machine learning algorithms to process publicly available global datasets is still emerging. Most existing research relies on regional or commercial data sources, while the use of open-source satellite layers like WorldCereal remains limited and primarily in the phase of validation and experimental deployment.

In this study, we propose the integration of the WorldCereal open dataset with both classical and advanced machine learning algorithms, including:

- Random Forest and XGBoost for crop type classification,
- K-means clustering for identifying agro-climatic patterns,
- and feature importance evaluation to support interpretability and decision-making.

Additionally, the study explores the potential for extending this methodology to other areas of precision agriculture, such as:

- detecting drought-prone regions,
- assessing erosion and land degradation risk,
- and fusing satellite data with drone imagery and IoT sensor networks at the local scale.

Our objective is to demonstrate how publicly available and globally standardized satellite data—such as the WorldCereal dataset—combined with open-source machine learning methods (e.g., Random Forest and XGBoost implemented in Python), can support the development of agricultural monitoring systems in data-scarce regions. This approach eliminates the need for expensive field equipment or proprietary software, making it suitable for use in countries with limited access to remote sensing infrastructure, local sensors, or high-performance computing resources.

The next section provides a detailed description of the materials and methods used in this study. Section materials and methods presents both quantitative and visual analyses of the classification and clustering results.

In the results and discussion section, we interpret the findings, examine limitations, and propose potential applications and integrations. Finally, Section conclusion summarizes the key insights and offers recommendations for future research directions.

MATERIALS AND METHODS

In this study, we conducted an empirical investigation of global cropland classification and agro-zone identification using the WorldCereal: Global Crop Type Product dataset at 10m resolution. This dataset, developed by the European Space Agency (ESA) and VITO Remote Sensing, served as the primary input for training supervised machine learning models (Random Forest, XGBoost) and applying unsupervised clustering techniques (K-means). Our research focuses on evaluating the performance of these models in accurately predicting crop types and delineating homogeneous agricultural zones using only satellite-derived attributes [1][2][4].

Key characteristics of the dataset include:

- Spatial resolution: 10 meters
- Geographic coverage: Global, with data available for agricultural regions worldwide
- Temporal coverage: Year 2021 (current version)
- Included layers (attributes):
- cropland_probability – probability that the area is cropland
- crop_type – crop classification (e.g., cereals, rice, maize)
- season – cropping season (spring, summer, winter)
- irrigated – irrigation status
- lat, lon – geographical coordinates
- confidence – classification confidence score
- additional NDVI layers derived from Sentinel-2 imagery (externally computed)

The data were downloaded in CSV format and prepared for analysis using Pandas and GeoPandas libraries in Python. For spatial visualization, folium, matplotlib, and seaborn were employed.

Upon acquisition, the dataset underwent a comprehensive preprocessing pipeline to ensure suitability for analytical modeling and evaluation. The first step involved removal of missing values in critical columns such as crop_type and cropland_probability, as these served as the foundation for both classification and clustering tasks.

Since the dataset comprised both numerical and categorical features (e.g., season, irrigated), categorical attributes were encoded into numeric representations, enabling seamless integration into machine learning pipelines. Particular attention was given to seasonal attributes, which carry strong spatial-temporal signals relevant to crop occurrence and dynamics [8].

Simultaneously, spatial distribution patterns were examined. Geographical coordinates (latitude and longitude) were normalized to eliminate outliers, and the data were spatially filtered to retain only agricultural zones with a high cropland probability, in alignment with the cropland_probability layer.

Based on externally derived NDVI values (Normalized Difference Vegetation Index) from Sentinel-2, additional variables were constructed to quantify vegetative intensity [3]. These features were instrumental in the unsupervised clustering phase aimed at identifying agro-ecological zones with similar characteristics [3].

To further refine class separability, binary indicators for irrigation status and seasonal cropping patterns were generated and incorporated into the modeling process [4].

The entire dataset was split into training and testing sets (70:30 ratio) while preserving the distribution of crop types across both subsets. This ensured representative sampling and reduced the risk of model bias. Standard preprocessing techniques such as scaling and label encoding were applied in accordance with best practices for implementing Random Forest and XGBoost classifiers.

This comprehensive data preparation laid a robust foundation for the deployment of classification models and enabled additional unsupervised learning via K-means clustering, which uncovered latent spatial patterns related to cropland distribution and crop diversity.

Random Forest is an ensemble learning method that builds a collection of decision trees during training and outputs the class that is the mode of the classes (for classification) or mean prediction (for regression) of the individual trees. The technique increases robustness and reduces the risk of overfitting by introducing two levels of randomness: sampling of the training data (bootstrapping) and random feature selection for each split in a tree.

For a given input instance $x \in R^d$, the prediction $\hat{y}$ is obtained as:

$$\hat{y} = majority\_vote\{h_1(x), h_2(x), ..., h_T(x)\} \qquad ....(1)$$

where $h_t(x)$ denotes the prediction of the t -th decision tree in the ensemble, and T s the total number of trees (in this research is T =50). Each tree is trained on a bootstrapped sample $D_t \subset D$, and at each node split, a random subset of features $F_t \subset F$ is considered, where:

$$|F_t| = \sqrt{|F|} \qquad ....(2)$$

for classification problems (common heuristic), ensuring diversity among the trees.

The model also provides feature importance estimates based on the average decrease in impurity (e.g., Gini index) across all trees, which is especially useful in the interpretation of high-dimensional datasets, such as satellite-derived agricultural layers.

XGBoost (eXtreme Gradient Boosting) is a high-performance implementation of gradient boosting decision trees, designed for speed, scalability, and predictive accuracy. The term "eXtreme" reflects several key innovations that go beyond classical gradient boosting:

- incorporation of regularization terms (L1 and L2) to reduce overfitting,
- parallelized tree construction,
- sparse-aware handling of missing data, and
- optimized memory usage and support for distributed computing environments [Wikipedia, NVIDIA].

Unlike traditional boosting methods that sequentially build weak learners to minimize prediction error, XGBoost employs a second-order Taylor expansion of the loss function, which allows it to incorporate both gradients and Hessians into the optimization process. This yields more precise model updates and significantly improves convergence speed.

The objective function in XGBoost balances model fit with complexity control by adding a regularization term that penalizes overly deep or complex trees.

The prediction function at iteration t is updated as:

$$\hat{y}_i^{(t)} = \hat{y}_i^{(t-1)} + f_t(x_i) \quad \text{................(3)}$$

Where f_t is the function learned at the t -th step (e.g., a decision tree), and $\hat{y}_i$ is the predicted value for sample i . The objective function to be minimized at each step consists of a differentiable loss function l , measuring the difference between the predicted and true values, and a regularization term $\Omega(f)$, that penalizes model complexity:

$$L^{(t)} = \sum_{i=1}^{n} l\left(y_i, \hat{y}_i^{(t)}\right) + \Omega(f_t) \quad \text{...................(4)}$$

The regularization term helps prevent overfitting and is defined as:

$$\Omega(f) = \gamma T + \frac{1}{2}\lambda \sum_{j=1}^{T} w_j^{\,2} \quad \text{..................(5)}$$

where:

- T is the number of leaves in the decision tree,
- w_j is the weight assigned to leaf j
- γ and λ are regularization hyperparameters.

By using a second-order Taylor approximation of the loss function, XGBoost achieves efficient optimization and supports parallel computation, making it well-suited for large-scale and high-dimensional datasets.

In the context of crop type classification using global satellite data (such as WorldCereal), XGBoost demonstrated excellent performance by capturing non-linear interactions between features like crop type, irrigation status, seasonality, and vegetation indices. Its robustness to noise and missing values further strengthens its applicability in precision agriculture, particularly for heterogeneous, real-world geospatial datasets [5][6][7].

Principal Component Analysis (PCA) is employed in this study as a dimensionality reduction technique and for the purpose of visualizing high-dimensional data in a two-dimensional space. The goal of PCA is to project the original dataset X into a lower-dimensional space Z , while preserving as much variance as possible. Mathematically, the transformation can be expressed as:

$$Z = XW \quad \text{.................(6)}$$

Where:

$X \in R^{n \times d}$ is the original data matrix,

$W \in R^{d \times k}$ is the matrix of eigenvectors (principal components) of the covariance matrix of X

$Z \in R^{n \times k}$ - is the transformed representation in the reduced k - dimensional space

PCA enables the identification of latent patterns and variance structures in the data, which is particularly valuable for exploring class separability, assessing data clustering tendencies, and facilitating visualization.

K-means Clustering is an unsupervised learning algorithm that partitions the dataset into K clusters by minimizing the within-cluster sum of squared distances between data points and their corresponding cluster centroids. The optimization objective is defined as:

$$\min_{\mu_1,\ldots,\mu_K} \sum_{k=1}^{K} \sum_{x_i \in C_k} \|x_i - \mu_k\|^2 \qquad \text{.................(7)}$$

Where:

- μ_k is the centroid of cluster C_k ,
- C_k is a set of instance given in that cluster .

In this study, K -means is applied in the PCA-reduced feature space, allowing the discovery of agro-climatic zones with similar geospatial and spectral characteristics, independent of any prior labeling. This unsupervised clustering contributes to the identification of regional patterns and structural groupings in agricultural land cover.

The original dataset used in this study contained geographical coordinates (lon, lat), crop labels (Crop), administrative boundaries (Country, State), and regional classifications (Region, Subregion, Continent, aez_id). All features were used either for exploratory data analysis, visualization, or filtering. Additional derived variables were generated during preprocessing, including numerical indices and NDVI-based estimates.

During exploratory data analysis, a set of visualizations was generated to assess feature distributions across crop classes. In Figure 1, we show the boxplot of a selected numeric variable, derived during feature extraction, across all labeled crop categories. This visualization helps identify inconsistencies, outliers, and heterogeneity within individual classes. Such intra-class variability is known to impair classifier accuracy, especially in multi-class settings, where clear feature separability is essential for reliable prediction.

RESULTS AND DISCUSSION

In the analysis conducted on the *world_cereals_scaled_final_all.csv* dataset — a preprocessed and feature-engineered subset derived from the WorldCereal: Global Crop Type Product (ESA/VITO, 2021) — a series of data preparation and modeling steps were carried out to classify crop types using global satellite indices and categorical attributes. (https://www.streambatch.io/knowledge/esa-worldcereal-global-crop-monitoring-at-field-scale). The original dataset was filtered to retain only high-probability cropland areas with valid crop type labels and enriched with externally computed NDVI features. Dimensionality reduction (PCA), statistical visualization (boxplots and violin plots), and supervised learning models (Random Forest, XGBoost) were then applied. Model performance was evaluated using confusion matrices and standard classification metrics.

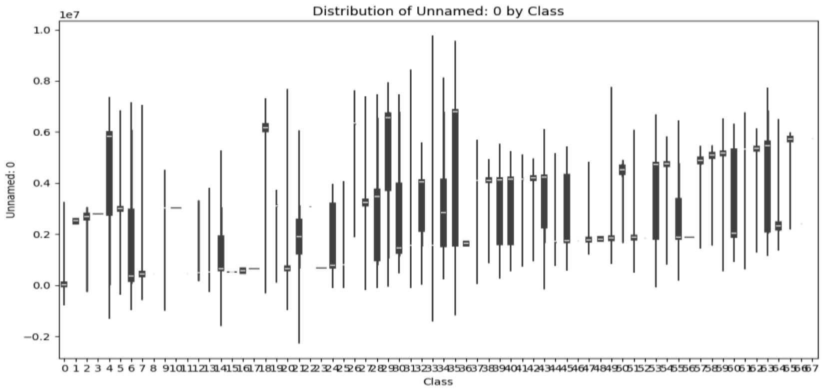

Figure 1. Boxplot distribution of a selected numerical feature across crop classes. The variable on the y-axis (Unnamed: 0) represents a numerical attribute derived from the WorldCereal dataset, associated with either NDVI-derived vegetation indices or a spatial indicator (depending on preprocessing pipeline version). Each boxplot summarizes the distribution of that feature within one crop class (x-axis), showing median, interquartile range, and outliers. High intra-class variance and the presence of outliers in several crop categories suggest heterogeneity in satellite signal representation for those crops, which may reflect mixed land cover, mislabeled samples, or seasonal overlap. These factors can negatively affect classifier performance by introducing ambiguity and reducing class separability.

The boxplot illustrates the distribution of feature values (likely locational or NDVI-related) across different classes, which represent either crop types or geographical entities. Considerable intra-class variability and the presence of outliers suggest heterogeneity within certain crop categories or possible mislabeling of samples. Such variance can negatively impact classifier performance and indicates the need for further class filtering or merging.

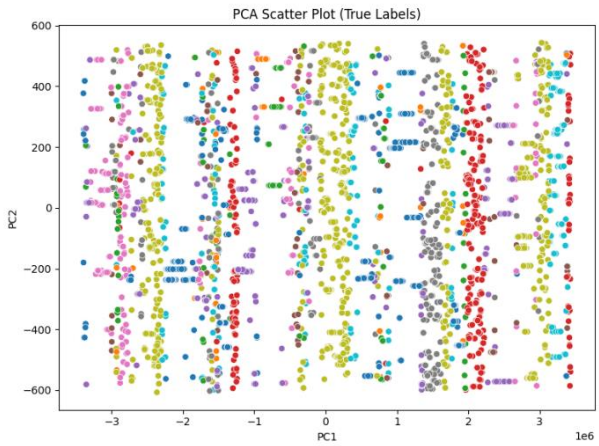

Figure 2. PCA scatter plot of crop type instances, colored by true class labels. Data was reduced to two principal components using PCA on standardized features from the WorldCereal dataset. The figure illustrates class structure and potential overlaps.

The PCA-based scatter plot (Figure 2) displays data instances projected onto the first two principal components, derived from standardized numerical features obtained from the WorldCereal dataset. The analysis was performed using Scikit-learn's PCA implementation in Python, and the resulting plot was generated by the authors using Matplotlib. While some class overlap is present — which is expected due to the high dimensionality and redundancy in spectral features — distinct groupings and isolated clusters can also be observed. These indicate that certain crop types exhibit unique spectral or temporal patterns, and that dimensionality reduction can reveal latent structures in the data, facilitating preliminary class separation and supporting downstream classification tasks.

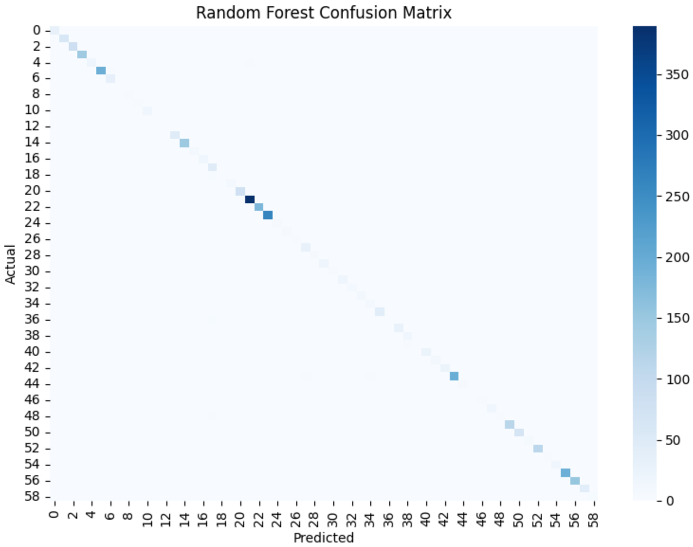

Figure 3. Confusion matrix for Random Forest classifier. Generated from the classification results on the test subset of the WorldCereal dataset using a Random Forest model implemented in Scikit-learn. Actual classes are shown on the y-axis, predicted classeson the x-axis. Color intensity represents the number of instances per class pair.

Figure 3 presents the confusion matrix for the Random Forest classifier trained on the preprocessed WorldCereal dataset. The matrix summarizes model performance across more than 60 crop classes and was generated using Scikit-learn, based on predictions on a held-out test set comprising 30% of the data.

The matrix demonstrates strong alignment along the diagonal, indicating high classification accuracy for the majority of classes. Misclassifications occur primarily between spectrally similar crop types, as also observed in the PCA projection.

Importantly, class distribution was sufficiently balanced to minimize model bias. The Random Forest model proved robust in handling high-dimensional and partially redundant datasets, leveraging its ensemble nature to effectively learn complex class boundaries. Higher misclassification rates were observed in rare classes with limited samples and overlapping spectral signatures.

The Random Forest classifier achieved an overall accuracy of 0.99 and a weighted F1-score of 0.98, demonstrating high precision and well-balanced performance across most classes. Major crop classes with large sample sizes (e.g., Classes 28, 29, 30, 50, 63, 64) achieved near-perfect classification results, with F1-scores ≥ 0.99. This underscores the model's ability to learn complex patterns and discriminate dominant crop types, even under high feature dimensionality.

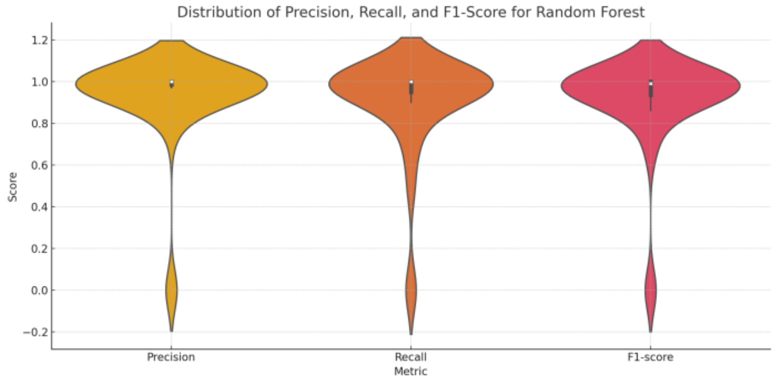

Figure 4. Violin plot of Random Forest performance metrics. To further investigate class-wise performance, we computed precision, recall, and F1-score for each crop class using predictions on the test set. Figure 4 shows the distribution of these metrics via violin plots. While the majority of classes achieved high precision and recall, a small number of minority classes showed significantly lower scores. This distributional view emphasizes the challenges in classifying underrepresented classes, despite the overall high average accuracy.

Despite these high scores, reduced performance was noted for minority and rare classes—especially Classes 25, 43, and 46—which had F1-scores of 0.00, indicating complete misclassification. These challenges stem from limited sample sizes and potential feature overlap with dominant classes. However, their impact on the overall weighted score is minimal due to their low representation.

The XGBoost model (Figure 5) delivered comparable overall performance to Random Forest, achieving a test set accuracy of 0.99 and a weighted F1-score of 0.99. However, macro-averaged precision (0.91) and recall (0.87) were slightly lower, reflecting greater variability across classes.

Figure 5 shows violin plots of the per-class precision, recall, and F1-score values obtained from predictions on the test set. These metrics were computed using classification_report from Scikit-learn, and the plot was generated in Seaborn. The distribution shapes indicate that while XGBoost performed well for dominant crop classes, a subset of minority classes exhibited low recall or F1-score — in some cases, being entirely missed (e.g., Classes 13, 15, 17).

XGBoost operates as a gradient boosting algorithm that sequentially adds decision trees to minimize a regularized loss function. Each tree in the ensemble focuses on correcting the residuals of the previous ones. Although it offers strong regularization and efficiency, the model tends to optimize toward well-represented classes unless explicit class weighting or sampling is applied.

This behavior is evident in the compressed lower tails of the violin plots, which represent underperforming or misclassified crop types.

One advantage of XGBoost lies in its stronger regularization and reduced risk of overfitting. However, it was observed to "ignore" underrepresented classes more frequently, especially when such classes lacked strong representation in tree splits.

While the overall accuracy appears impressive, per-class evaluation highlights the issue of sample imbalance, which can lead to the marginalization of low-frequency classes. This is a typical problem in multiclass datasets with skewed class distributions and should be addressed through additional techniques such as SMOTE (Synthetic Minority Oversampling Technique), weighted loss functions, or aggregation of similar classes.

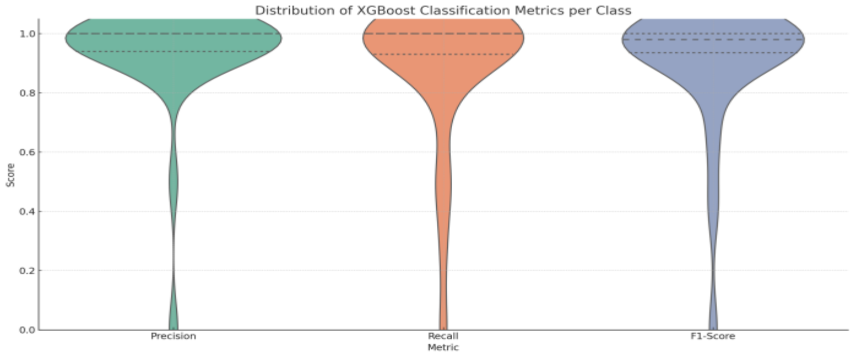

Figure 5. XGBoost performance – violin plot. The distribution reflects performance variability across crop types. Metrics were computed using Scikit-learn based on test set predictions, and the plot was generated using Seaborn.

Table 1. Overall performance comparison of Random Forest and XGBoost classifiers based on test set predictions. Metrics computed using Scikit-learn.

Model	Accuracy	Macro F_1	Weighted F_1
Random Forest	0.99	0.91	0.98
XGBoost	0.99	0.88	0.99

Table 1 summarizes the classification results of both models on the test set. Metrics were computed using Scikit-learn’s classification_report function. Accuracy refers to the overall proportion of correct predictions. Macro F1 represents the unweighted mean F1-score across all classes, while Weighted F1 accounts for class imbalance by weighting each class’s F1-score by its support. These results confirm that both models performed well, with slight differences in class-wise stability.

Both models demonstrated high overall accuracy, yet they differed in performance patterns across classes. Random Forest exhibited greater stability when dealing with rare or underrepresented classes, owing to its inherent ability to distribute attention evenly across samples. In contrast, XGBoost achieved superior performance in well-represented classes, attaining an exceptionally high weighted F1-score, but at the cost of diminished recall for minority classes.

This discrepancy underscores the importance of selecting classification algorithms in accordance with the class distribution and intended use case. While Random Forest ensures more balanced classification, XGBoost can provide sharper delineation for dominant patterns, especially in large-scale datasets.
These findings highlight the trade-offs involved in ensemble model selection and emphasize the need for careful model evaluation depending on dataset imbalance and application objectives [1].

CONCLUSION

This study experimentally demonstrated the applicability of ensemble-based machine learning models—namely Random Forest and XGBoost—for the classification of crop types and the identification of agro-ecological zones using globally available satellite data.

By utilizing the open-access WorldCereal dataset (ESA, 2021), and applying tailored preprocessing, it was possible to classify over 60 crop categories with exceptionally high accuracy (F1-score $\geq$ 0.98 for major classes).

The models were trained and evaluated on a representative subset of global cropland areas, with input features including crop type, seasonality, irrigation status, and derived NDVI indices. Despite the complexity of the multi-class setting and the presence of underrepresented categories, Random Forest showed greater robustness to class imbalance, while XGBoost delivered sharper delineation for dominant crop types.
Additionally, the use of Principal Component Analysis (PCA) for feature space reduction and K-means clustering for unsupervised agro-zone identification confirmed the potential to group agriculturally similar regions without prior labeling. This opens perspectives for developing self-organizing systems for land use monitoring, especially valuable in regions lacking extensive ground-truth data.

Importantly, the methodology proposed in this research is fully implementable using Python and relies exclusively on publicly accessible data, making it suitable for low-resource settings. The framework is not limited to crop type classification alone, and can be extended to related domains such as irrigation optimization, stress detection, soil monitoring, or yield prediction.

Overall, the study provides a reproducible, scalable, and data-driven approach for supporting precision agriculture through machine learning, with direct implications for regions with limited local infrastructure and growing needs for sustainable agricultural practices.

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PRIMENA GLOBALNIH SATELITSKIH PODATAKA I MODELA MAŠINSKOG UČENJA ZA KLASIFIKACIJU USEVA I IDENTIFIKACIJU AGRO-ZONA

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Abstrakt: Ova studija predstavlja primenjen pristup korišćenju globalno dostupnih satelitskih podataka, konkretno WorldCereal baze – za klasifikaciju i prostornu analizu poljoprivrednog zemljišta. Dataset, razvijen u okviru Evropske svemirske agencije (ESA), sadrži informacije o tipu useva, verovatnoći obradivosti zemljišta, sezonalnosti i statusu navodnjavanja za 2021. godinu, u rezoluciji od 10 metara. Nakon filtriranja na osnovu visoke verovatnoće poljoprivredne upotrebe, implementirani su algoritmi Random Forest i XGBoost za klasifikaciju tipova useva, kao i nenadgledano K-means klasterovanje za identifikaciju agro-zona sličnih karakteristika. Glavne kategorije useva uključuju žitarice, kukuruz, pirinač i mahunarke. Metodologija je testirana na velikom podskupu globalnog skupa podataka, koristeći Python-baziranu analitičku obradu.

Naši rezultati pokazuju da modeli mašinskog učenja mogu postići visoku tačnost klasifikacije (F1 ≥ 0.98) čak i uz ograničen broj ulaznih parametara, dok klaster analiza otkriva konzistentne prostorne obrasce bez prethodnog označavanja.
Ovi nalazi ističu potencijal otvorenih satelitskih podataka i modelovanja zasnovanog na podacima u razvoju ekonomičnih i skalabilnih sistema za preciznu poljoprivredu, naročito u regionima bez detaljnih podataka sa terena.

Ključne reči: *daljinska detekcija, klasifikacija pokrivenosti zemljišta, stabla algoritama učenja, analiza prostornih podataka, mapiranje navodnjavanja, mašinsko učenje.*

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ADVANCED PHOTONIC TECHNOLOGIES IN PRECISION AND DIGITAL AGRICULTURE

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Abstract: Photon-based technologies, grounded in the controlled application of light energy, are becoming a key component of modern digital and precision agriculture. This article examines three complementary approaches: laser-based targeted weed control, UV-C light for managing fungal diseases, and laser-induced breakdown spectroscopy (LIBS) for soil analysis. Each of these technologies offers high spatial and spectral selectivity, automation potential, and the ability to reduce reliance on chemical agents and conventional laboratory diagnostics. We present the scientific foundations of each approach, current applications, agronomic effects, and technical challenges, and analyze their potential integration into broader agro-digital systems. Special emphasis is placed on the role of photonics in the transition toward environmentally responsible, low-input, and data-driven food production. This contribution provides a foundation for further research and practical implementation of these technologies across diverse crop production models.

Key words*: photonics, laser-based weed control, UV-C radiation, LIBS, soil analysis, precision agriculture, agricultural digitalization, agro-optical technologies*

INTRODUCTION

Over the past two decades, agriculture has been increasingly oriented toward data-driven and technologically enhanced systems grounded in the principles of sustainability, efficiency, and precision [8]. This transformation commonly referred to as precision agriculture (PA), digital agriculture, or smart farming encompasses a wide range of technologies aimed at optimizing agronomic decision-making based on spatial, temporal, and biological data.

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One of the fastest-growing yet still underintegrated segments of this paradigm is photonics the science and technology of using light to detect, process, and interact directly with biological systems. In agricultural contexts, photonics refers to the application of optical approaches including laser, LED [7], UV, and spectroscopic technologies for monitoring plants, soil, and the environment, or for conducting precise interventions without the use of chemical agents. As an interdisciplinary field, it merges the physics of light, sensor technology, plant biology, and agronomic practice. Photonics offers high spatial and spectral selectivity, rapid responsiveness, and automation capabilities, positioning it at the forefront of developing environmentally responsible technologies for crop production. This paper explores three key areas of advanced photonic technology applications in agriculture:

- Laser-based targeted weed control, which provides a precise and environmentally friendly alternative to herbicides. Through the integration of computer vision, artificial intelligence, and high-energy laser beams, this method enables selective ablation of weeds without mechanical soil disturbance or damage to the cultivated crop.
- The use of ultraviolet-C (UV-C) radiation for fungal disease suppression in plants as a substitute for conventional fungicides. UV-C light, with wavelengths between 200 and 280 nm, damages the nucleic acids of pathogens and inhibits sporulation, leaving no chemical residues in plant tissues or the environment.
- Laser-induced breakdown spectroscopy (LIBS) as an innovative method for soil analysis. LIBS enables rapid, multi-element, reagent-free quantification of macro- and micronutrients in soils, supporting precision fertilization and sustainable fertility management.

All three technologies share common characteristics: they enable contactless, selective, and often automated operation; they do not require chemical inputs; and they are suitable for integration with existing digital platforms such as robots, unmanned aerial vehicles, and sensors. Furthermore, these technologies are increasingly paired with artificial intelligence and machine vision, allowing for complex real-time detection and response. There is a growing body of literature demonstrating the efficacy of these photonic approaches. For example, laser systems developed by companies like Carbon Robotics [3] have achieved up to 95% weed control efficacy in field trials without phytotoxic effects. Night-time UV-C treatments have reduced powdery mildew incidence in cucumbers by more than 80% without negatively impacting photosynthetic efficiency. In soil diagnostics, modern LIBS platforms have shown potential to replace classical chemical analyses with accuracy comparable to reference methods such as ICP-OES.

Despite their promise, these technologies face several challenges: high initial equipment costs, the need for precise calibration and standardization protocols, and limited practitioner familiarity with their operation in agricultural practice. It is therefore essential that equipment development be paralleled by studies on the physiological, developmental, and resistance-related impacts of light-based interventions under diverse climatic and agro-ecological conditions.

The aim of this article is to present the underlying scientific mechanisms, technological implementation, and application potential of selected photonic approaches, while critically evaluating their utility and commercial prospects across various crop production models from high-tech greenhouses to extensive field systems. The article concludes with a discussion on synergies between photonic technologies and other components of precision agriculture, and outlines directions for future research and knowledge transfer to practice.

MATERIAL AND METHODS

Laser-Based Targeted Weed Control

Mechanism of Action and Scientific Basis

Laser-based weed control is founded on the focused application of a high-energy, coherent electromagnetic beam that selectively damages the apical meristem of weeds by inducing localized thermal ablation. The thermal effect leads to protein denaturation and rupture of cell membranes, resulting in irreversible necrosis of vegetative tissue. Crucial to this process is the precise targeting of high energy-density pulses to regions with elevated mitotic activity, which prevents regeneration and leads to complete cell death. The most commonly used sources are high-energy pulsed infrared diode lasers, typically operating at powers between 5 and 150 W and within the spectral region around 980 nm. With pulse durations ranging from microseconds to milliseconds, local temperature increases exceeding 2000 °C can be achieved sufficient to vaporize cellular contents or even induce plasma phenomena. Within the WeLASER project [14], successful results were recorded, achieving up to 98% weed mortality at energy doses below 10 J/cm². Target identification is conducted via multispectral image analysis [9], supported by deep learning algorithms (e.g., convolutional neural networks CNNs), which enable the distinction between crop plants and weeds based on morphological and spectral features. High-resolution actuators (precision below 0.5 mm) then direct the laser beam precisely to the identified target. This approach allows for selective ablation even at early phenological stages of weed development (cotyledon–2 leaf stage).

Practical Applications

In commercial settings, laser systems are primarily employed in high-value horticultural crops, where chemical control is either restricted or prohibited. The LaserWeeder™ system [3] is based on an architecture comprising several dozen synchronized laser emitters and a 12-sensor imaging module, enabling the simultaneous treatment of thousands of targets per hour. Empirical data from Braga Fresh farms in California [3] indicate a 70% reduction in weed removal costs and over 95% weed control efficacy.

In Europe, the WeLASER project [14] is developing a fully autonomous tracked robotic platform equipped with spectroscopy-enhanced laser modules for precise intra-row weed management. Field trials on crops such as maize, sugar beet, and triticale demonstrate the potential to replace herbicides with high selectivity and minimal soil disturbance.

Companies Developing Solutions

In addition to Carbon Robotics, several European companies are advancing laser weed control technologies. For example, Futonics Laser (Germany) is developing laser sources with high photothermal efficiency.

Extensive validations are underway within public-private partnerships involving leading research institutions such as Wageningen University & Research and INRAE. The prevailing model consists of modular systems that can be mounted on conventional tractors or integrated into standalone robotic units.

Advantages and Limitations Compared to Conventional Methods

Advantages

- Agrochemical-neutral approach: Complete elimination of herbicide use, which is particularly beneficial for organic farming systems.
- Sub-millimeter precision: Minimizes the risk of off-target damage to cultivated crops.
- High level of automation: Compatible with autonomous systems for continuous, unattended operation.
- Preservation of soil biodiversity and physical integrity: Maintains soil aggregate structure and protects the soil microbiome (edaphon).
- Limitations and Constraints
- Capital-intensive initial investment: High equipment costs and the need for advanced technical training.
- Limited throughput per hectare: Current systems are optimized for horticultural or specialty crops.
- Operational complexity: Sensitive to dust, humidity, and thermal stability of system components.
- Optical safety requirements: Implementation must comply with Class 4 laser safety standards (IEC 60825-1).

Commercial Viability and Future Outlook

Laser technologies are currently most commercially established in the United States, particularly in the segment of intensive vegetable production. Return on investment (ROI) estimates for areas exceeding 80 hectares suggest payback periods of between 1 and 3 years. In Europe, implementation remains in its early stages, with several pilot projects underway and the development of rental-based business models (e.g., Robot-as-a-Service), which could lower the adoption barrier for medium-sized and specialized farms. In conclusion, laser weed ablation represents a high-tech alternative to chemical and mechanical weed control methods, demonstrating strong potential for integration into sustainability-oriented agroecosystems that demand precision, selectivity, and environmental non-invasiveness.

Application of Ultraviolet-C (UV-C) Radiation

Mechanism of Action and Scientific Basis

Ultraviolet-C (UV-C) light, within the spectral range of 200–280 nm and with peak germicidal efficacy around 254 nm, exerts its effect through photochemical damage to nucleic acids (DNA and RNA), resulting in inhibited cell division and apoptotic death of microorganisms. UV-C photons induce the formation of cyclobutane pyrimidine dimers (CPDs) and 6-4 photoproducts [14, 7], which disrupt transcription and replication processes in pathogenic microbes.

Pathogenic fungi such as powdery mildews (*Erysiphales*) and downy mildews (*Peronosporaceae*) possess some capacity for photoreactivation via photolyase enzymes, whose activity is triggered by exposure to blue light (400–500 nm). Consequently, a key insight in the modern application of UV-C in crop protection is the strategy of irradiating plants in the absence of light at night or before sunrise to avoid activation of DNA repair mechanisms in pathogens. The optimal UV-C dose is determined by balancing the minimum lethal dose for pathogens (typically 40–120 J/m²) against the sub-phytotoxic threshold for cultivated plants. Exceeding this threshold can lead to oxidative stress, photobleaching, or necrotic lesions in leaf tissue. In practical terms, fluence (J/m²) is systematically defined based on the spectral intensity of the UV source (W/m²) and the exposure duration (s), in conjunction with a mobile lighting platform positioned above the plant canopy.

Practical Applications

The most advanced implementation of UV-C technology in agriculture is based on autonomous robotic platforms (e.g., Thorvald by Saga Robotics, TRIC Robotics), which perform nocturnal irradiation of crop rows using mounted low-pressure mercury lamps or UV-C LED panels. Field trials in vineyards [10], particularly on Chardonnay grapevines, demonstrated over 90% reduction in powdery mildew incidence with weekly treatments. Similarly, trials on Fragaria × ananassa (strawberries) showed that UV-C exposure significantly reduced the incidence of Botrytis cinerea and powdery mildew [4], while maintaining yields comparable to conventional fungicide programs. In addition to fungal pathogens, UV-C radiation also affects certain arthropods. For instance, exposure of mites and thrips to sublethal UV-C doses can lead to sterilization or inhibition of development. This combined pathogen and vector suppression effect grants UV-C technology considerable practical value.

Leading Industry Applications

Among the leading technology developers in the field of UV-based plant protection is TRIC Robotics (USA), which offers nocturnal UV-C treatment services for strawberry fields using autonomous robotic platforms specifically designed to reduce fungicide use. Saga Robotics (Norway) commercializes the modular Thorvald robotic platform, equipped with integrated UV-C light modules for systematic vineyard treatment against powdery mildew and other fungal pathogens. CleanLight [4] manufactures both stationary and mobile UV-C systems, including UV-LED panels for greenhouse use, with more than 5,000 implementations across various horticultural sectors.

Noteworthy among emerging innovators is Antobot (UK), which is developing compact autonomous robotic carriers for UV-C technology, and the French company UV Boosting, which introduces a spectral-temporal modulation approach ("priming") using low-intensity UV-B pulses to activate systemic plant immunity. Both companies represent forward-looking, non-chemical plant protection strategies based on photonic technologies.

Advantages and Limitations Compared to Conventional Methods

Advantages

- No chemical residues: UV-C leaves no residues, enabling production without preharvest intervals.

- No selective pressure: Pathogens do not develop resistance to the physical mode of action.
- Multifunctionality: Simultaneous effects on fungi, bacteria, and certain insect pests.
- Compatibility with organic farming and integrated pest management (IPM).
- High level of automation: Enables autonomous nighttime operation, reducing labor requirements.

Limitations and Constraints

- Lack of systemic effect: Acts only upon contact and requires repeated applications.
- Limited penetration: UV-C does not penetrate deep into the canopy; effectiveness depends on plant architecture.
- Phototoxicity risk: Overexposure may cause plant damage such as necrosis or bleaching.
- Operational logistics: Requires nighttime operation, energy supply, and adherence to safety protocols.

Commercial Viability and Future Potential

UV-C technologies are currently most widely adopted in high-intensity fruit and vegetable production systems with high market value. Business models such as "UV-as-a-Service" (e.g., TRIC, Saga) and proprietary equipment systems (e.g., CleanLight) provide diverse entry points for farms of varying sizes. The application of UV-C is particularly promising within the context of European policies aimed at pesticide reduction (e.g., the "Farm to Fork" strategy) and the development of more resilient agroecosystems. Rooted in the principles of photobiology and optoelectronics, this technology when effectively integrated with digital agro-platforms is emerging as a core component of the future paradigm of low-input, sustainable, and data-driven crop production.

Laser-Induced Breakdown Spectroscopy (LIBS)

Mechanism of Action and Scientific Basis

Laser-Induced Breakdown Spectroscopy (LIBS) is a high-resolution spectroanalytical technique in which a nanosecond or picosecond pulse from a high-energy laser (typically Nd:YAG, λ = 1064 nm) is focused onto the surface of a solid sample (e.g., dried and homogenized soil), causing localized ablation of the material and the generation of plasma within a microexplosion.

This plasma, heated to temperatures exceeding 10,000 K, emits spectrally distinct lines corresponding to the elemental composition of the sample. Through spectroscopic detection using a CCD-based system coupled with an echelle spectrometer, it is possible to simultaneously detect a broad range of elements across the spectrum (200–900 nm), including light elements such as carbon (C) and nitrogen (N), which are not detectable using conventional methods such as X-ray fluorescence (XRF).

A distinctive advantage of LIBS is its capacity for quasi-real-time analysis with minimal sample preparation simple drying and granulometric homogenization are sufficient. Averaging thousands of laser pulses per sample reduces variability and allows for reliable quantitative interpretation.

Using multivariate regression models (e.g., Partial Least Squares Regression PLSR, Principal Component Regression PCR) or machine learning approaches (e.g., support vector machines, convolutional neural networks), LIBS spectral data can be transformed into predictive models [2, 6] for agronomic parameters such as concentrations of macronutrients (K, Mg, Ca, P), micronutrients (Zn, Cu, Fe), total organic carbon (TOC), and soil texture. One of the main challenges is the so-called matrix effect the influence of the soil's physical and chemical properties on the intensity of emission lines which is addressed through complex calibration using a representative set of reference samples.

Practical Applications

Over the past decade, numerous validation studies have confirmed a strong correlation between LIBS-based predictions and standard laboratory methods such as ICP-OES, Kjeldahl, and Walkley-Black. For example, the portable Z-300 LIBS spectrometer (SciAps, USA) [11] achieved an $R^2 > 0.88$ when estimating total organic carbon (TOC) in soil samples from the United States and Canada, demonstrating high utility for assessing soil quality and organic fertilization needs. The most widely adopted system in practice is LaserAg (LogiAg, Canada) [8], where samples are compressed into pellets and analyzed with 3,000 laser pulses in just a few seconds. The system supports routine measurement of nutrients, pH, particle size distribution, and organic matter. Commercial laboratories such as Eurofins in Canada and Omnia in South Africa are already using LaserAg in operational settings. With an analysis time of less than five minutes per sample, the system enables high laboratory throughput and rapid feedback to users. In research contexts, efforts are underway to integrate LIBS sensors into field platforms (e.g., tractors, robots) to enable in-situ soil analysis during field operations. These sensors are expected to generate high-resolution spatial maps of soil nutrient levels (more than one sample per 10 m^2), which could significantly enhance the accuracy of variable-rate fertilization.

Companies Developing Solutions

Among the leading industrial players in LIBS technology for agronomic applications is the Canadian company LogiAg, which developed the comprehensive LaserAg laboratory system. This includes the Quantum spectroscopic unit, integrated multivariate analytics software, and data interfaces for GIS platforms. LaserAg is designed as a high-throughput solution for commercial laboratories, enabling automated acquisition and interpretation of spectral data using thousands of laser pulses per sample. The U.S.-based company SciAps developed the portable LIBS unit Z-300, designed for rapid in-field diagnostics. The device supports assessment of parameters such as total organic carbon (TOC) and potentially macronutrients (P, K, Mg), with region-specific calibrations.

Due to its robustness and speed, the Z-300 is increasingly used in pilot projects focused on precision fertilization. Another notable company is Applied Spectra, which develops high-resolution laboratory LIBS systems with combined analysis capabilities (e.g., LA-ICP-MS) for complex, multipurpose research.

Their instruments are employed in environmental, agroecological, and soil science studies requiring high sensitivity and analytical resolution. On the research and development front, numerous institutions are actively contributing to the field, including the Institute of Soil Science at Zhejiang University (China), the University of São Paulo (Brazil), and Cornell University [5].

Their work supports the standardization of LIBS protocols, development of algorithms to correct for matrix effects, and integration of spectroscopic data with advanced artificial intelligence methods. Promising approaches include the development of portable units integrated with autonomous platforms for real-time soil mapping.

Advantages and Limitations Compared to Conventional Methods

Advantages

- Rapid analysis: Measurement time is less than 5 minutes per sample.
- Multi-element detection: Simultaneous quantification of macro- and micronutrients, including light elements.
- No chemicals or waste: Environm. friendly laboratory process without reagents.
- Minimal sample preparation: Eliminates time-consuming preparation steps.
- Field applicability: Potential for decentralized, in-field diagnostics using portable units.

Limitations and Constraints

- Calibration dependency: Requires region-specific models due to matrix effects.
- Limited sensitivity: Not comparable to ICP-MS for trace heavy metal detection.
- Interpretability of results: Often provides total elemental concentrations rather than extractable fractions.
- High equipment costs: Initial investment exceeds €50,000 for portable systems and €200,000 for laboratory-grade setups.

Commercial Viability and Future Potential

LIBS technology represents a critical component in the transition toward data-driven precision agriculture. Its capability for rapid, multi-element, reagent-free soil analysis aligns well with the ongoing digitalization of agroecosystems. Provided that instrumentation becomes more widely accessible, analytical precision improves, and standardized measurement protocols (e.g., ISO accreditation) are adopted, LIBS is likely to become an integral part of both laboratory-based and field-based agronomic diagnostics over the next decade. Thanks to its compatibility with geographic information systems (GIS), artificial intelligence algorithms, and autonomous platforms, LIBS is positioned as a promising solution for the advancement of regenerative and sustainable agriculture.

Comparison of Existing Photonic Technologies in Precision and Digital Agriculture

To provide a comprehensive overview of the comparative advantages and limitations of the discussed photonic technologies within the context of precision and sustainable agriculture, Table 1 presents a synthesized comparison.

It systematically outlines key technical parameters, agronomic performance capabilities, and the commercial maturity level of each technology. Additionally, information on leading technology providers and their application strategies is included to facilitate a better understanding of the relationship between innovative light-based approaches and conventional methods for crop protection and soil analytics.

Table 1. Comparative Overview of Photonic Technologies in Precision and Digital Agriculture

Technology	Leading Providers	Key Advantages	Key Limitations	Current Status and Accessibility
Laser-based weed control	Carbon Robotics (USA) LaserWeeder™. WeLASER (EU project) autonomous laser prototype for field crops. Startups and ongoing research (Germany, Netherlands)	Herbicide-free (suitable for organic farming). High precision; selectively targets weeds among crops. Reduces manual labor- Preserves soil structure. Avoids erosion.	High equipment cost. Slower coverage on large fields (currently suited for vegetables)- Technically demanding maintenance- Less effective on mature weeds	Commercially available for specialized crops (vegetables, horticulture). Primarily sold in the U.S. EU projects in prototype stage. Early adopters report 70–80% reduction in weeding costs.
UV-C light for disease control	TRIC Robotics (USA). UV-C robots for strawberries (as-a-service). Saga Robotics (Norway/New Zealand). Thorvald UV robot for vineyards. CleanLight (Netherlands). Antobot + CleanLight (UK). compact UV robot for tunnels. Others in development (e.g., Icaro X4)	Fungicide-free (no residues, no resistance development). Broad spectrum efficacy (fungi and some pests). No preharvest interval. suitable for organic farming. Automation allows nighttime operation	Frequent treatments required (e.g., weekly). Only effective at night (requires robotic platform). Limited light penetration (less effective in dense canopies). High initial equipment cost (robot or system)	Already in practical use: vineyards, berries (e.g., strawberries), and greenhouses. Commercially available as a service (TRIC) or equipment (CleanLight). Rapid adoption in high-value niche markets
LIBS soil analysis	LogiAg LaserAg. (Canada). SciAps Z-300 (USA)	Rapid multi-element analysis. Reagent-free (no chemical waste). High repeatability (less error in preparation). Portable field diagnostics possible	Requires region-specific calibrations (due to matrix effects). Limited sensitivity for trace elements. Results often reflect total rather than extractable content. High equipment cost.	Used in select laboratories. Handheld analyzers available only for experts, not yet routine but advancing rapidly broader adoption expected with growth of precision agriculture.

RESULTS AND DISCUSSION

A comprehensive review of current scientific and technical literature reveals that photonic technologies particularly UV-C illumination, laser-based weed control, and laser-induced breakdown spectroscopy (LIBS) constitute a technological foundation for the transition toward more precise, environmentally compatible, and data-driven agriculture. The reviewed studies consistently demonstrate that UV-C light effectively reduces fungal disease incidence across various horticultural crops (e.g., *Botrytis cinerea* in strawberries and grapes), with application efficacy strongly dependent on spectral intensity and temporal exposure dynamics. Systematic reviews also emphasize that UV-C treatments significantly reduce fungicide use, especially in organic production systems. For laser-based weed control, the literature confirms it as a highly precise method, particularly effective for selectively targeting weeds during early developmental stages. The technology shows strong potential for organic farming contexts where chemical weed control is not permitted, though it requires precise optoelectronic plant tracking and high-energy laser sources. Data from multiple reviews and meta-analyses [e.g., 16, 13] indicate that LIBS provides a multi-element, rapid, and reagent-free method for determining soil chemical composition. The strong correlation between LIBS outputs and standard chemical analyses (e.g., ICP-OES, TOC) demonstrates the method's value, particularly for precision fertilization and monitoring of soil resources. Key advantages also include compatibility with artificial intelligence algorithms and the potential for integration into autonomous field platforms. Based on the comparative synthesis, each technology demonstrates specific utility within distinct segments of agricultural practice:

- UV-C is optimal for intensive fruit and vegetable production systems.
- LIBS is most applicable in arable farming and sustainable agronomy, where rapid, spatially resolved soil data are essential.
- Laser-based weed control is emerging in organic farming systems as a high-tech alternative to herbicides.

The literature also highlights several challenges and limitations, including the energy demands of laser systems, the need for calibration models in LIBS, and regulatory considerations surrounding UV-C as a phytosanitary measure. A crucial factor for real-world implementation is user education and the availability of technical know-how, prompting authors to recommend the development of dedicated training programs. In conclusion, the reviewed photonic technologies form a synergistic ensemble that not only complements existing methods but also enables a transformation of agriculture toward greater precision, reduced environmental impact, and enhanced responsiveness to agroecological dynamics. Continued research, validation across diverse agroclimatic regions, and the standardization of measurement protocols will be key to their long-term adoption.

CONCLUSIONS

This study provides a comprehensive examination of advanced photonic technologies and their current and potential applications within precision and digital agriculture.

By analyzing three core technologies laser-based targeted weed control, ultraviolet-C (UV-C) radiation for plant disease suppression, and laser-induced breakdown spectroscopy (LIBS) for soil analysis the research outlines both the scientific mechanisms underpinning these approaches and their agronomic relevance. Findings from peer-reviewed studies and field validations confirm that photonic systems offer substantial advantages in terms of spatial selectivity, chemical-free operation, and automation readiness. UV-C light has demonstrated consistent efficacy in suppressing fungal pathogens across various high-value horticultural crops, with significant reductions in fungicide usage, particularly in organic systems. Laser weeding has proven to be a highly accurate method for non-contact weed removal, especially in early developmental stages, with applications particularly suited to organic horticulture.

LIBS, on the other hand, enables rapid, multi-element, and reagent-free soil diagnostics, providing actionable insights for nutrient management and supporting the principles of site-specific fertilization. Despite their promise, each technology is associated with specific operational and technical challenges: laser systems are capital-intensive and require optoelectronic precision, UV-C treatments must be timed to avoid pathogen photorepair mechanisms, and LIBS depends on complex calibration models to mitigate matrix effects. Furthermore, regulatory, economic, and knowledge-transfer barriers remain significant factors influencing adoption rates (7). Nevertheless, these technologies collectively form a synergistic toolkit that aligns with global sustainability goals, offering pathways to reduce chemical inputs, enhance resource use efficiency, and improve resilience in agroecosystems. Their integration into digital agricultural frameworks alongside artificial intelligence, GIS systems, and autonomous platforms marks a pivotal step toward next-generation farming systems.

The continued development and deployment of these photonic solutions will require targeted research, robust validation across agroclimatic zones, standardization of protocols, and dedicated training for end-users. As such, photonics holds the potential not only to augment but to fundamentally transform how we monitor, manage, and optimize crop production in an era increasingly defined by ecological constraints and technological possibilities.

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NAPREDNE FOTONSKE TEHNOLOGIJE U PRECIZNOJ I DIGITALNOJ POLJOPRIVREDI

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Apstrakt: Tehnologije zasnovane na fotonima, na kontrolisanoj primeni svetlosne energije, postaju ključna komponenta moderne digitalne i precizne poljoprivrede.
Ovaj članak prikazuje tri komplementarna pristupa: ciljano suzbijanje korova zasnovano na laserima, UV-C svetlost za suzbijanje gljivičnih bolesti i laserski indukovana spektroskopija razgradnje -LIBS, za analizu zemljišta.
Svaka od ovih tehnologija (metoda) nudi visoku prostornu i spektralnu selektivnost, potencijal automatizacije i mogućnost smanjenja oslanjanja na hemijske agense i konvencionalnu laboratorijsku dijagnostiku.
Predstavljene su naučne osnove svakog pristupa, trenutne primene, agronomski efekti i tehnički izazovi, i analiza njihove potencijalne integracije u šire agro-digitalne sisteme. Poseban naglasak je stavljen na ulogu fotonike u prelasku ka ekološki odgovornoj, niskoinvesticionoj i podacima vođenoj proizvodnji hrane.

Ovaj doprinos pruža osnovu za dalja istraživanja i praktičnu primenu ovih tehnologija u različitim modelima proizvodnje useva.

Ključne reči*: Fotonika, suzbijanje korova pomoću lasera, UV-C zračenje, LIBS, analiza zemljišta, precizna poljoprivreda, digitalizacija poljoprivrede, agrooptičke tehnologije.*

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DESIGN MODELLING OF STAND-ALONE SOLAR PHOTOVOLTAIC SYSTEMS FOR A THREE-ROOM BUNGALOW IN UMUAHIA CITY, ABIA STATE, NIGERIA

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Abstract: This study looks at the layout, operation, and feasibility of a stand-alone solar photovoltaic (PV) system for a three-room bungalow in Umuahia, Abia State, Nigeria. The solar panel, charge controller, battery, and inverter are the primary design elements of the solar photovoltaic system. It was found that the daily energy usage was 21 kWh, which translated into a total wattage of 2.4 kW. Twenty (20) solar panels with a 435 W capacity each were chosen for the SPV system. The actual current amperage of the solar charge controller was 102 A, and its power rating was 8.7 kW, as per the SPV design. The solar system was anticipated to require twelve (12) batteries, and the SPV system design chose one battery with a 250 Ah capacity. It was discovered that the inverter's input power was 3.2 kVA. The maximum DC direct current and voltage are 192 A and 24 V, respectively.
The maximum alternating current and voltage for the SPV system were 11 A and 230 V, respectively. The highest number of solar panels was observed in August, when the sun's output was at its lowest.

Since the estimated actual energy output per day (21 kWh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow.
The solar performance ratio came out to be 85.5%.

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***Key words**: Design; solar energy photovoltaic system; module, charge controller, battery; inverter; output power; solar radiation; performance ratio.*

INTRODUCTION

Urban areas in Abia State, Nigeria, are grappling with significant energy challenges. The electricity supply in these regions is characterized by its unreliability, high cost, and frequent outages, which significantly impact residential buildings. Despite efforts to enhance electricity consumption, urbanization, and economic growth [26]. The allocation of electricity remains skewed, and about 91% of the electricity supply is directed to urban areas, leaving rural areas with minimal access due to constraints in the electrical grid [38]. This disparity exacerbates the difficulties faced by both urban and rural dwellers in accessing stable and reliable electricity [20]. Consequently, approximately 80% of those connected to the grid resort to using fossil fuel generators as an alternative source of electricity [29], highlighting the persistent imbalance between electricity demand and supply. The exploration of renewable energy sources has been proposed as a potential solution to the inadequate electricity supply in Nigerian urban center's, including Abia State [35]. Research has been conducted to assess how households adapt to insufficient electricity supply, their use of renewable energy facilities, and their perceptions of renewable energy sources [35]. However, the use of solar energy has become an alternative solution to free from irregular power supply to commercial buildings in Umuahia city [34]. In addition, the transition to renewable energy sources is challenged by infrastructure development, cost implications, and policy frameworks. The historical context of Nigeria's electricity supply sector reveals persistent issues such as gas shortages, power asset insecurity, high operational costs, and insufficient capital for consistent performance [30]. These challenges hinder the efficiency and reliability of the sector, affecting both urban and rural areas. Privatization of Nigeria's energy sector has not fully addressed these issues, with investors facing numerous obstacles that impede sector growth and development [30]. There is a clear need for modernization and prioritization of the electricity sector to ensure a sustainable and reliable supply [20]. Innovative approaches, including the use of machine learning for modelling electricity supply dynamics, have been explored to enhance understanding and address challenges within the sector [3]. Electricity is a critical driver of economic growth in developing countries, emphasizing the importance of ensuring an efficient and sustainable supply [3]. Despite these efforts, the gap between electricity demand and supply persists, necessitating innovative solutions to meet the growing energy needs of urban areas like Abia State.

In urban Abia State, the inadequate electricity supply impacts not only residential buildings but also small-scale industries, where reliable power is essential for operations [33]. Cost-effective solutions such as stand-alone power generation systems have been proposed to address the electricity needs of these industries, highlighting the importance of consistent and affordable power sources [33]. Additionally, the design and evaluation of solar electricity systems for administrative buildings reflect ongoing efforts to enhance energy access and reliability in urban settings [19]. Compounding these challenges are issues such as electricity theft, distribution inefficiencies, and inadequate power generation [28]. These long-standing issues have led to frequent outages and unreliable electricity supply for urban residents [28].

The ramifications are extensive, affecting not only residential buildings but also businesses, industries, and overall economic productivity in urban areas. In conclusion, the background of electricity supply in urban Abia State, Nigeria, underscores a complex interplay of factors, including disparities in supply allocation, reliance on alternative power sources, exploration of renewable energy, infrastructure limitations, and policy challenges. Addressing these issues requires a multifaceted approach that integrates renewable energy solutions, infrastructure development, policy reforms, and investment in modernising the electricity sector to ensure a sustainable, reliable, and cost-effective electricity supply for residential buildings and urban areas. Solar photovoltaic systems are based on the direct conversion of solar irradiation into electrical energy through the photovoltaic (PV) method [8]. These systems are composed of micro- and nanostructured electrodes that facilitate solar energy conversion, either in the form of photovoltaics or direct photo-electrolysis cells [41]. The principles and composition of solar photovoltaic systems have been applied in various settings, including maritime vessels, buildings, and apartment buildings, to harness renewable energy for power generation [24,25,36]. Additionally, research has focused on optimising the performance of photovoltaic solar electric power through intelligent systems using light-dependent resistors and servo motors for automatic solar tracking [14]. Furthermore, numerical simulations have been conducted to study heat transfer in concentrating solar photovoltaic systems, aiming to enhance their efficiency [39]. The integration of solar photovoltaic systems with thermoelectric generators has also been explored to improve energy generation and efficiency [23]. Moreover, the application of solar thermal power generation technology has been investigated as a complementary approach to solar photovoltaic systems, contributing to the overall development of renewable energy technologies [22]. Solar photovoltaic systems harness sunlight and convert it into electricity through the photovoltaic effect, where photovoltaic cells, typically made of semiconductor materials, directly convert solar radiation into electrical energy [37]. When sunlight strikes the photovoltaic cells, the energy of the photons in the sunlight is transferred to the electrons in the semiconductor material, causing the electrons to be expelled and creating an imbalance of charge that results in the generation of an electric current [37]. This direct conversion of sunlight into electricity is a fundamental principle of solar photovoltaic systems and has been the focus of technological advancements aimed at increasing efficiency and performance. One significant technological advancement in the field of solar photovoltaics is the development of solar cells with higher conversion efficiencies. Research has shown that increasing the efficiency of solar cells is crucial for improving the overall performance of photovoltaic systems [13].

This has led to the exploration of innovative approaches, such as splitting sunlight into spectral bands and directing each band to a dedicated solar cell with an appropriate energy bandgap to maximize conversion efficiency [13]. Additionally, advancements in semiconductor materials and the design of photovoltaic cells have contributed to improving the efficiency of solar energy conversion [37]. Another area of technological advancement in solar photovoltaic systems is the development of intelligent systems for solar tracking and energy extraction improvement. Research has focused on the implementation of automatic solar tracking systems using light-dependent resistors and servo motors to optimize the energy produced from photovoltaic cells, making the overall systems more efficient and cost-effective [32].

Furthermore, the reconfiguration strategies for electrical PV arrays have been investigated to improve energy extraction and adapt to external operating conditions, enhancing the overall performance of grid-connected PV systems [32]. Moreover, the integration of solar photovoltaic systems with grid-connected inverters and the development of advanced control techniques have been significant technological advancements in the field. These advancements aim to improve the power quality, efficiency, and reliability of grid-connected photovoltaic systems, contributing to their seamless integration with existing electrical distribution systems [9,16].

[1] emphasizes the broad applicability of solar energy in Nigeria, spanning across agriculture, engineering, medical sciences, power generation, and recreation, showcasing its versatility and potential impact on various sectors. [12] delves into the adoption of renewable energy and green technology in Nigeria, specifically noting the increasing trend of solar PV adoption in cities like Kano, where 60% of adopters installed their systems between 2015 and 2016, indicating a growing interest in solar energy among residents. [2] focused on the determinants of solar energy use by small and medium enterprises in Lagos State, pointing out that factors such as the cost of grid electricity, poor utility services, and government policies significantly influence the adoption of solar energy as an alternative power source. Moreover, [27] have explored the geospatial assessment of suitable sites for utility-scale solar PV farms in Nigeria, revealing the untapped potential for solar energy generation in the country, with locations capable of producing significant amounts of solar electricity annually. [31] conducted a viability assessment of a grid-integrated solar PV system in Idofian, Nigeria, showcasing practical applications of solar technology in enhancing electric power supply in specific regions. These studies collectively underscore the growing interest and practical implementations of solar energy solutions in Nigeria, particularly in urban areas where the demand for reliable and sustainable power sources is increasing. Furthermore, the challenges and serviceability of solar power in Nigeria have been addressed by [40], who suggest solutions to the energy crisis by incorporating solar energy into the country's energy mix, highlighting the potential gains that Nigeria can achieve through solar energy integration. Factors influencing solar PV utilization among residents in specific urban areas like Akure have also been investigated by [18], shedding light on the determinants that impact the adoption and utilization of solar energy technologies in different regions. These studies provide valuable insights into the practical implications, challenges, and opportunities associated with solar energy adoption in residential buildings within urban areas of Nigeria. In conclusion, recent research on solar energy in residential buildings in urban areas of Nigeria reflects a growing trend towards the adoption and integration of solar power as a viable solution to the country's energy challenges.

From exploring the diverse applications of solar energy to assessing the factors influencing its adoption and conducting geospatial assessments for optimal solar PV farm locations, these studies collectively contribute to the body of knowledge aimed at promoting sustainable and renewable energy practices in Nigeria's urban settings. As the country continues to grapple with energy issues, the findings from these studies serve as valuable resources for policymakers, urban planners, and stakeholders seeking to leverage solar energy for a more sustainable and resilient energy future in Nigeria.

MATERIAL AND METHODS

Geographical and Climatic Profile

Figure 1 shows that Umuahia, the capital city of Abia State, Nigeria, is approximately 5.53°N latitude and 7.49°E longitude. Its location close to the equator endows it with a tropical rainforest climate characterised by substantial rainfall and consistently high temperatures. The average annual temperature in Umuahia ranges from 24°C to 28°C, with relative humidity levels often exceeding 80%. This climate profile is essential for understanding the region's solar energy potential. The significant solar irradiance levels in Umuahia make it an advantageous area for solar photovoltaic (PV) applications. High temperatures and humidity must be factored into the design and efficiency calculations for solar PV systems to ensure they can withstand local climatic conditions.

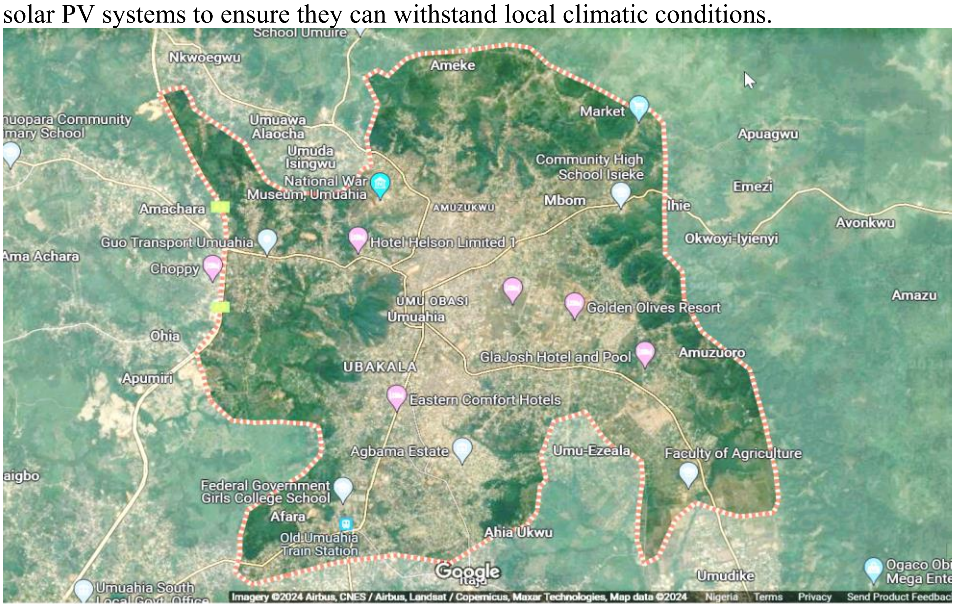

Figure 1. Map showing Umuahia, Abia State, Nigeria

Demography of Umuahia

Umuahia, the capital city of Abia State, Nigeria, exhibits a complex demographic profile crucial for understanding the potential implementation of hybrid solar photovoltaic systems in residential areas.

The city is divided into two Local Government Areas (LGAs): Umuahia North and Umuahia South, comprising urban and rural communities [15]. The population of Umuahia is characterized by a high proportion of individuals in their reproductive years. According to a study on socioeconomic factors in Umuahia, the majority of women of childbearing age fall within the 25-29 age group (30.0%), followed by those under 25 (23.8%) and those aged 30-34 (21.9%) [15]. This age distribution suggests a relatively young population, which could affect energy consumption patterns and the adoption of solar technologies. Education levels in Umuahia are notably high, with 45.2% of the studied population having tertiary education and 44.0% having secondary education [15].

This high level of education could facilitate residents' understanding and acceptance of solar energy technologies.

The Methodology

In this section, we will give a technical overview of the system components. Also, design methods and mathematical calculations for sizing these components are presented [4].

The solar photovoltaic system's primary parts are:

(1) Solar PV panel array, (2) Batteries, (3) Solar charge controllers (SCC), and (4) Inverter

PV System Design

The following steps conduct the system design calculations:

(1) Estimating the total load of all appliances in the three-room bungalow.

(2) Sizing the solar PV system. This includes selecting the type of PV panels, number of panels, arrangement of PV array, and the orientation of panels (i.e. tilt angle).

(3) Sizing the battery bank, (4) Sizing the Inverters, (5) Sizing the solar charge controller.

Estimating Total Daily Load

The total load includes all electrical appliances, such as lighting and equipment, that are used daily in the bungalow. The average daily solar insolation is mainly taken as 5 kW/m^2/day.

PV array Sizing:

Standard Testing Conditions (STC) involve 1 kW/m^2 of irradiation and a PV cell temperature of 25°C.

The Exact Design -Method 1.

The PV panel is characterized by its average efficiency, ηp, which is a function of average panel temperature as given by [4], and is presented in eqn. (1).

$$\eta_p = \eta_r\left(1 - \beta_p\left(T_p - T_r\right)\right) \qquad \text{.....................................(1)}$$

where η_r Is the panel efficiency at T_r. T_r Is the reference temperature (25 ^{0}C). β_p It Is the temperature coefficient for module efficiency. The value of η_r and β_p Appendix A shows 20.1% and -0.38%/K, respectively.

T_P is a function of the ambient temperature, as stated by [4], and is given in eqn. (2).

$$T_p = T_a + \left(219 + 832\bar{k}\right)\left(\frac{NOCT-20}{800}\right) \qquad \text{..........................(2)}$$

Where $\bar{k}$ It is the clearness index. It ranges from 0.3 for cloudy areas to 0.8 for sunny areas. T_a is the ambient temperature of the solar panel (30 ^{o}C). NOCT is the Nominal operating cell temperature (45 ^{o}C).

The total area S_A Of the PV panel array can be presented in Eq. (3) as stated by [10]

$$S_A = \frac{E_p}{\eta_p\, G} = \frac{E_p^!}{\eta_c \eta_b \eta_p\, G} \qquad \text{..........................(3)}$$

Where: E_p Does the PV array provide the energy?
$E_p^!$Is the energy provided by the PV array after the battery bank
($E_p^!$Equals the daily load demand 20,690 Wh).
G is the daily irradiance (5kWh/m^2/day),$\eta_{c,}$ $\eta_b$and η_i Are the efficiencies of the controller, batteries, and inverter, respectively (η_c = 95%; η_b = 90%; η_i = 96%).
The area of a SunPower 435W single solar panel S_p is equal to 2.067m ×1.046m =2.16 m^2 as in Appendix A.
The number of SPV panels as stated by [4] is given in Eqn. (4)

$N_{p1} = S_A/S_p$ ……………………………(4)

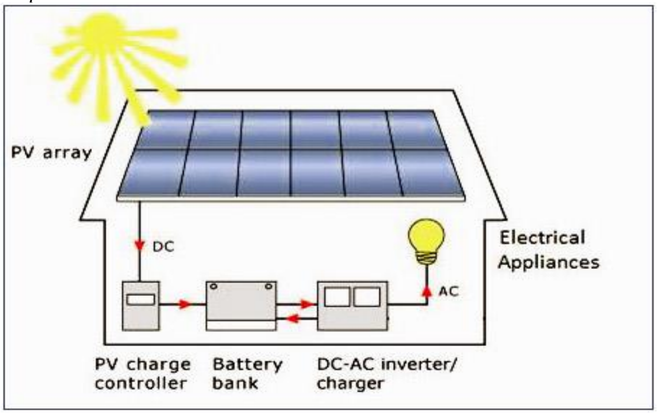

Fig. 2. Solar PV system design.

The size of the solar panel and module estimation for method 2.
The total electricity demand of the bungalow in Umuahia from the gathered data in Table 1 is used to determine the size of the PV system (in Wp).
The SPV Module Peak Wattage Estimation (Wp) according to [5] is presented in Eqn. (5).

The total watt hour (Energy) using battery efficiency (η_b) of 90%.
Module Peak wattage (Wp) = $\frac{\Sigma(\text{Daily Energy Demand Wh})}{PSH \times \eta_b}$ …….(5)
Where PSH is peak sunshine hours and η_bIs the battery efficiency.
Number of Modules or panels = $N_{P2} = \frac{\text{SPV Module Wattage Estimation}}{\text{Value of Each Panel}}$ …….(6)
The SunPower panel of 435 W was selected for the solar design.

The size of the solar panel for method 3
The total appliances used per day = energy consumed per day (ECPD) = **20,690** Wh/day

Total PV panels energy needed (TPEN)
$TPEN = ECPD \times ELS$ ………………..…(7)

Total Peak Wattage (Wp) of PV panel capacity needed (PWSP)= PGF x WSP
The total number of solar panels (N_{P3}) according to [21] is given in Eqn. (8).

$$N_{P3} = \frac{\text{Energy watt hour per day x Energy loss in the system}}{Panel\ generation\ factor\ (PGF) \times Wattage\ of\ single\ panel (WSP)} = \frac{TPEN}{PWSP} \quad \text{.........(8)}$$

The energy loss in the solar system (ELS)= 1.3

Panel generation factor (PGF) = 3.596 for Nigeria.
The minimum clearance (distance) required between each row of panels is represented by distance (d) as seen in Plate 1 and Omni calculator calculates the angles in Fig. 3.

This distance can be calculated using the equation. (9) as stated by [4].

$$d = h[(\sin(180^o - \beta - \gamma_s))/(sin\gamma_s)] \quad \text{..............(9)}$$

Determining this clearance requires the angle γ_s Of the sun at midday (12 Noon) in the shortest day of the year 2023 (i.e., 21st December). The angle (γ_s) is 60.27 ° (see Fig. 3). The collector height used is ≈ 1.8 m. The tilt angle used is β = 15 °.

Hence, the distance is ≈ 2m.

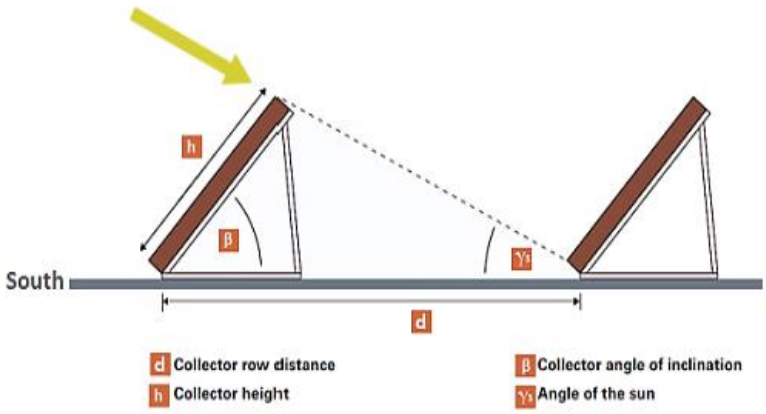

Plate 1. Clearance Between Collectors or PV Panels Rows

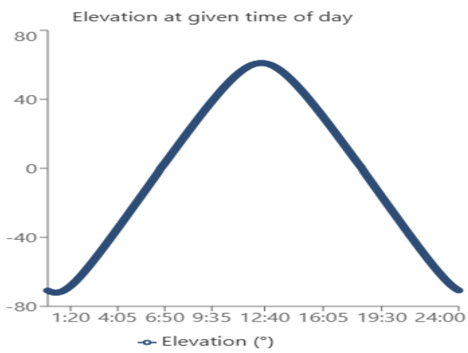

Fig.3. The angle γ_s of the sun at midday in the shortest day of the year 2023 (21st December) for the Umuahia area (by Solar elevation angle Omni calculator).

The battery sizing of the solar panel (Method 1), according to [11], is presented in Eqn. (10).

The actual battery capacity = $B_{C1} = \frac{\text{Total Energy (Wh)}}{\text{Depth of Discharge} \times \text{System Volt}}$ …...(10)

The system voltage used for this system is 12 volts and 0.5 depth of discharge.

Number of batteries = $N_{B1} = \frac{\text{Actual Battery Capacity}}{\text{Value of Each Piece}}$

The battery sizing of the solar panel (Method 2) as given by [21] is presented in Eqn. (11).

The actual battery capacity = $\frac{\text{Total Energy (Wh) x Days of autonomy}}{\text{Battery loss x Depth of Discharge} \times \text{System Volt}}$ …… (11)

The nominal battery voltage is 12 volts; Battery loss is 0.85; depth of discharge is 0.6, and Battery days of autonomy is 2.

Number of batteries = $N_{B2} = \frac{\text{Actual Battery Capacity}}{\text{Value of Each Piece}}$ …………….(12)

Since 250Ah batteries can be easily found in the market and have more storage capacity, the final calculation is selected to determine the actual number of batteries for the solar panel design.

The Charge Controller Selection for Method 1.

To obtain the needed charge controller as given by [7] is represented in equation (13) Solar Charge Controller (SCC_{1cu}) is given below.

$SCC_{1cu} = \frac{\text{Total Wattage}}{\text{Voltage}}$ ………………………(13)

The system voltage used is 24 V.

The Solar charge controller sizing: Method 2, according to [21], is given in eqn. (14).

According to standard practice, a solar charge controller sizing is to take the short circuit current (Isc =6.43 A from Appendix A) of the PV array and multiply it by the Energy panel loss (ELS-1.3).

Solar charge controller rating (SCC_{2cu})

SCC_{2cu} = panels in Series array x total short circuit current of PV array x 1.3 …...(14)

The solar charge controller sizing SCC_3cu for Method 3.

The charge controller's rated power is greater than the maximum power the PV array could produce, since a safety factor 1.3 is used.

The following are the steps to determine the SCC_{3cu} by [4] presented in Eqn. (15).

(1). Wattage of the PV array = (number of PV panels)×(PV panel rated power) .....(15)

(2). Rated voltage of SCC_{3v} = (number of panels in series) × (Voc of panel) ………(16)

(3) Rated current of SCC_{3cu}=(number of strings of panels)×(Isc of PV panel)×(safety factor)

3.2.9. The Inverter Capacity Selection for the solar panel as stated by [7;8] is in eqn. (17) for Method 1.

Therefore, Input Power = $\frac{\text{Output Power}}{\text{Efficiency of inverter } (\eta_i)}$ ………………………(17)

The inverter sizing for Method 2 as presented by [21] is stated in Eqn. (18).

For safety, the inverter should be considered 25-30% bigger than the total wattage of all appliances.

$$Inverter\ Input\ power = 30\% \times total\ wattage + total\ wattage \qquad \text{......(18)}$$

3.3.1. The Output Power from the SPV system according to [5]is given in Eqn. (19).

$$P_{out} = G \times S_{tp} \times \eta_{sys} \qquad \text{..........................(19)}$$

Where (S_{tp}) Is the area of the SPV panel array, (η_{sys}) Is the panel system efficiency; G is the solar radiation.

The maximum direct/alternating current and voltage of wire of the solar photovoltaic system as given by [6,7] are represented in eqns. (20) and (21).

$$\text{The maximum direct current (DC)} = \frac{Max\ DC\ wattage\ (W)/module\ \ wattage}{DC\ system\ voltage\ (V)} \qquad \text{.....(20)}$$

The maximum DC voltage and current are 24V and 711.6A.

$$\text{The maximum alternating current (AC)} = \frac{Max\ AC\ wattage\ (W)/Total\ \ wattage}{AC\ system\ voltage\ (V)} \text{.....(21)}$$

The maximum AC voltage and current are 230V and 44.7 A.

Solar Performance Ratio (SPR%) according to [16;17;18] is stated in equation (23)

$$SPR(\%) = \frac{Actual\ Energy\ Output}{Theoretical\ Maximum\ Energy\ Output} \times 100 \qquad \text{...........(22)}$$

$$SPR(\%) = \frac{Daily\ Energy\ Demand\ (Wh)}{total\ solar\ area\ (m^2) \times panel\ efficiency (\eta_r) \times Insolation\ \ G\ (\frac{kwh}{m^2})} \times 100 \qquad \text{......(23)}$$

G Solar insolation on tilted panel (kWh/m^2/day):

η_r = Total solar panel efficiency (%).

S_A =Total solar area (m^2).

Table 1. Energy Consumption of a Typical Three-room Bungalow in Umuahia City.

S/N	Appliances	Power Rating (W)	Quantity	Total Power (W)	Hours of Daily Usage	Daily Energy Consumption (Wh)
1	LED light bulb	5	10	50	12	600
2	Fan	75	5	375	7	2625
3	Refrigerator	760	1	760	12	9120
4	Television	110	2	220	5	1100
5	Air conditioner	1,20	1	1,200	5	6000
6	Sound system	250	1	250	3	750
7	DSTV	20	2	40	5	200
8	Phones	1	5	5	5	25
9	Power Bank	18	3	54	5	270
Total				2,439		20,690

Table 2. Weather parameters from the Meteorological Unit at NRCRI.

Daily average solar radiation and ambient temperature from January to December. 2023, and Theoretical Output Power				
S/N	Solar Radiation (G_r) (W/m^2)	Ambient temperature (Ta) (°C)	Theoretical Monthly Output Energy (kWh)	Actual Monthly Output Energy (kWh)
1	5192	27.61	4626	642
2	6508	29.76	5980	580
3	4588	28.94	4001	642
4	4384	28.38	4149	621
5	3536	28.74	3040	642
6	2512	27.41	2258	621
7	2432	27.11	2202	642
8	1780	27.24	1620	642
9	2300	27	2060	621
10	2528	27.76	2295	642
11	4120	27.32	3677	621
12	4980	29.11	4611	642

Table 3. The Characteristics of The SPV System

Solar Photovoltaic Panel Capacity	435 W
Type	E 20/435 Solar Panel
Manufacturer	SunPower
Model	SPR-435NE-WHT-D
Number of Modules	20
Efficiency	20%
Nominal operating cell temperature	45%
Temperature coefficient	-0.38%/K
Solar collector area	2.16 m^2

RESULTS AND DISCUSSION

The design results from the SPV system.

Table 1 shows the collected data from a bungalow in Umuahia city, while Table 4 reveals the actual results from the design analysis of the proposed solar photovoltaic system. The environmental weather parameters, such as solar radiation and ambient temperature, were collected from the meteorology unit inside the National Root Crops Research Institute (NRCRI) for 12 months in 2023

Table 4. shows the results from the proposed SPV design of a three-room bungalow in Umuahia.

	Total energy in Watt-hours (kWh)	Wattage (kW)	Number of solar components	Capac. of the single product (W)	Input power (kW)	Ampere (A)	Volt (V)	Efficien. (η %)
Solar panel	21	2.4	20, 19 & 18	435				20

Contin. Table 4.								
Charge contr.		9				428,75 &75	684.8	95
Battery (Ah)			12& 27	250				90
Inverter					2.5 &3.2			96
Max. DC.						192	24	
Max. AC.						11	230	
SPR								85.5

Discussion of results in Table 3.

Table 1 displays the three-room bungalow's energy estimate, while Table 4 summarizes the determined design outcomes. The analysis found various energy-consuming appliances with different power ratings and operating times. It was determined that the facility (solar panel) would use 20,690 Wh (21 kWh) of electricity each day.

The estimated module peak power for the solar photovoltaic panel was 4,598 W (4.6 kW). For the SPV design, a SunPower single solar panel with a wattage of 435 W was chosen. The results of methods 1, 2, and 3 showed 20, 19, and 18 solar panels, respectively. Method 1 was chosen to design the solar photovoltaic system since it has the most panels (20). The efficiency of the solar panels was found to be 20%. Methods 1, 2, and 3 all yielded solar charge controller amperages of 102 A, 41.8 A, and 33.1 A, respectively. For the SPV system design, the best result (102 A) from approach 1 was chosen. 8.7 kW was determined to be the solar charge controller's wattage. There were 12 batteries from method 1 and 27 batteries from method 2.

Even though procedure 2 produced the maximum number of batteries, the number of batteries from method 1 (12) was chosen for the SPV system design. While method 2's outcome is required in situations when high energy storage is crucial, method 1's result is economically feasible. The 250 Ah single solar lithium-ion battery was used for the design because it was readily available and had a good product storage capacity. The inverter's input power was 2.5 kW for method 1 and 3.2 kW for method 2. Method 2 is used to design the SPV system because it has the largest inverter input power (3.2 kW). The suggested SPV system has a maximum direct current (DC) of 192 A and a maximum voltage of 24V. The SPV system's maximum voltage and alternating current (AC) were 230V and 11 A, respectively. The solar system's solar performance ratio was 85.5%, indicating that it effectively transforms sunlight or solar irradiance into electrical power. Table 1 shows that appliances with large energy demands, including air-conditioners and refrigerators, dominate consumption. Their respective energy demands are 6,000 and 9,120 Wh. Other appliances, including fans, TVs, and LED lightbulbs, use less energy on their own, but they add to the total demand because of their longer use hours. However, it can usually be optional. The availability of solar energy is aligned with the peak energy demand, which usually happens during the day when operating activities are at their highest [4;10;11;12].

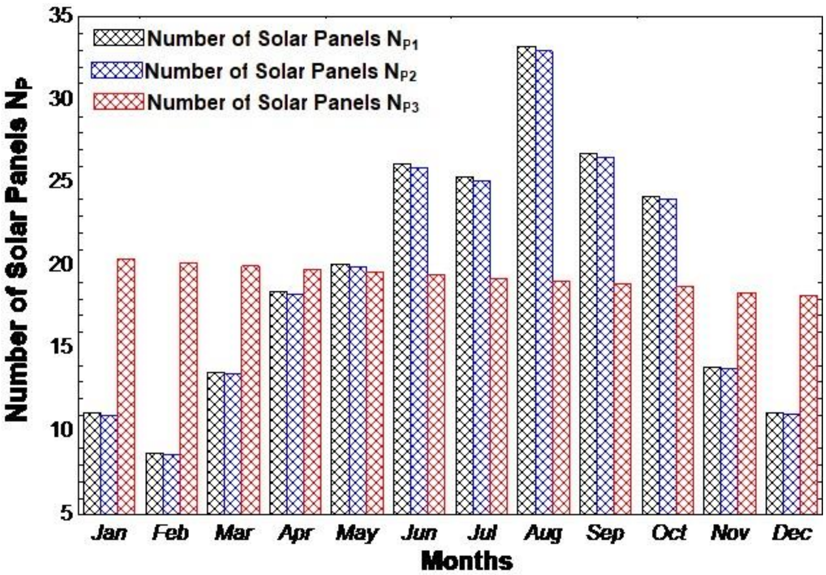

Fig. 4. The Number of panels of the solar photovoltaic system

Fig. 4 shows the number of solar panels calculated from three methods, and they were simulated by the Engineering Equation Solver (EES) software. The total summation, average, minimum, and maximum number of panels (N_{P1}) from method 1 are 232.7, 19.39, 6.7, and 33.24, respectively. The number of solar panels obtained from method 2 was also simulated, and the total summation, average, minimum, and maximum number of panels (N_{P2}) are 230'6, 19.22, 8.625, and 32.94, respectively.

The total summation, average, minimum, and maximum number of solar panels (N_{P3}) from method 3 are 232.2, 18.31, 16.89, and 20.41, respectively. It can be observed that method 1 has the highest average number of solar panels of 19.39, and it is approximated to be 20 for the SPV design, which aligns with the findings of **[4,5].** Another observation from the bar chart is that the results from method 3 are higher from January to April and become lowest from May to October. The results from methods (1 and 2) are higher during the rainy season, while method 3 is higher in the dry season. It can also be seen in the bar chart that during the rainy season, there is always poor solar radiation or sunshine; therefore, a greater number of solar panels will be needed, as observed in August, which recorded 125.7 maximum number of solar panels.

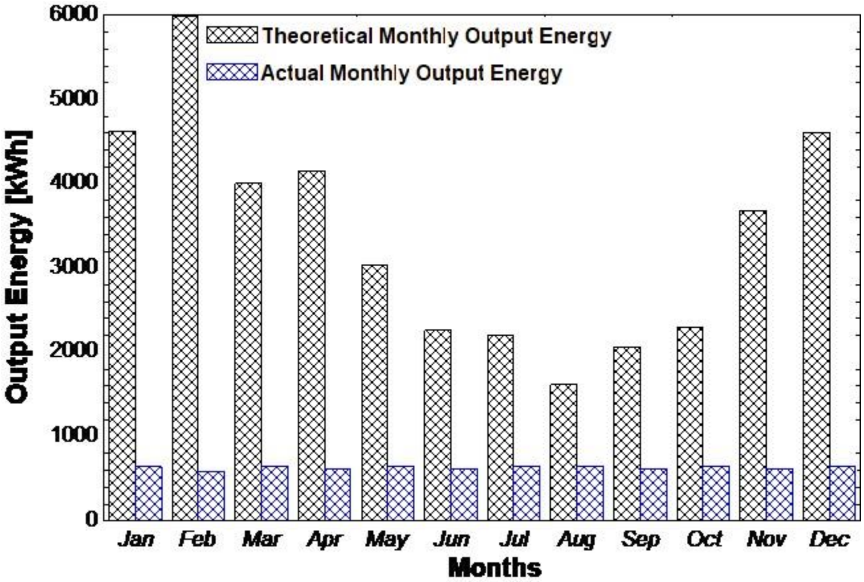

Fig.5. The output power from the solar photovoltaic system

Fig. 5 is the output energy from the solar photovoltaic system. The summation, average, minimum, and maximum theoretical output energy were 40519, 3377, 1620, and 5980 kWh, respectively, while the summation, average, minimum, and maximum actual output energy from the appliances were 7558, 630, 580, and 642 kWh, respectively. The overall theoretical energy generated by the system in a year is 40519 kWh, with an average monthly energy production of 3377 kWh. Since the estimated actual energy output per day (21 kWh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow.

The findings regarding the highest output energy in February and the lowest in August are consistent with [11,19,28]'s observations.

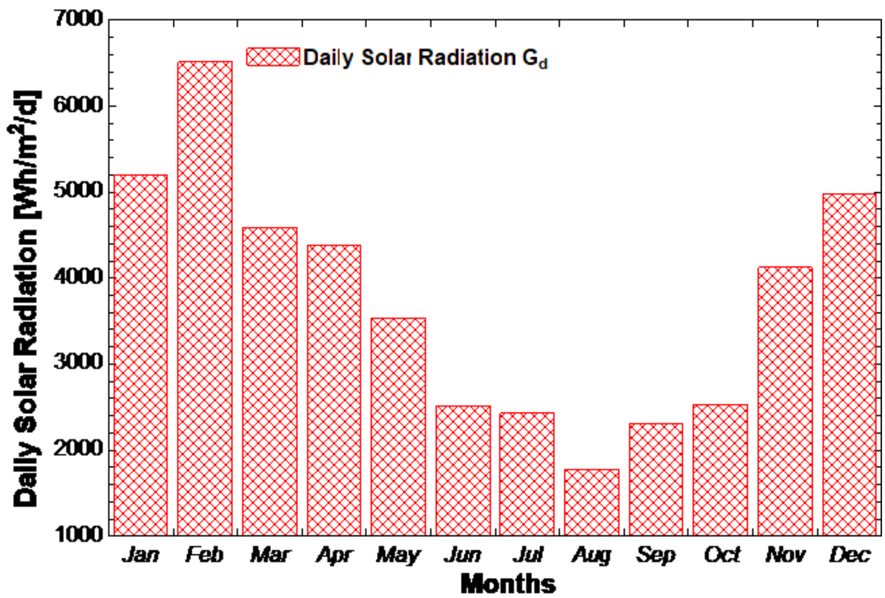

Fig.6. The solar radiation for the photovoltaic system

The solar radiation bar chart for the photovoltaic system from January to December 2023 is shown in Fig. 6. Solar radiation was at its lowest in August and then rose from September to February. In August, the average, minimum, and maximum sun radiation summary were 44300, 1780, 800, and 3800, respectively. In February, the average, minimum, and maximum solar radiation summary were 162700, 6508, 3200, and 8400, respectively. Accordingly, February 2023 saw the highest amount of solar radiation in Umuahia, Abia State, while [8,9,10] found a similar outcome. This is because February had the highest solar radiation, resulting in a maximum output energy of 239.2 kWh per day compared to Table 1's Actual consumption energy of 21 kWh daily.

CONCLUSION

The proposed design of a standalone solar photovoltaic system for a three-room bungalow in Umuahia City, Abia State, Nigeria, has been completed. The major findings of the solar photovoltaic system are: The energy requirement per day was 21 kWh, and the total wattage becomes 2.4 kW. The number of solar modules or panels obtained was 20. The SunPower solar panel of 435 W was selected to design the SPV system. The current amperage of the solar charge controller realized was 102 A for the SPV design, and the power rating for the charge controller was 8.7 kW. The number of batteries calculated for the solar system was 12, and 250 Ah for a single battery was chosen for the SPV system design. The input power of the inverter was determined to be 3.2 kW for the SPV system design. The proposed SPV system's maximum direct current DC and voltage were 192 A and 24 V, respectively.

At the same time, the maximum alternating current AC and voltage for the SPV system were 11 A and 230 V, respectively. It was observed that the highest number of solar panels occurred in August, during the period of minimum solar radiation**.** The proposed SPV system will meet the energy needs of the three-room bungalow, since the estimated actual energy output per day (21 kwh) and monthly average output energy (630 kWh) were below the monthly minimum (1620 kWh) and maximum theoretical output energy (5980 kWh), the solar photovoltaic energy will meet the energy requirement of the three-room bungalow. The solar performance ratio of the solar system was determined to be 85.5 %.

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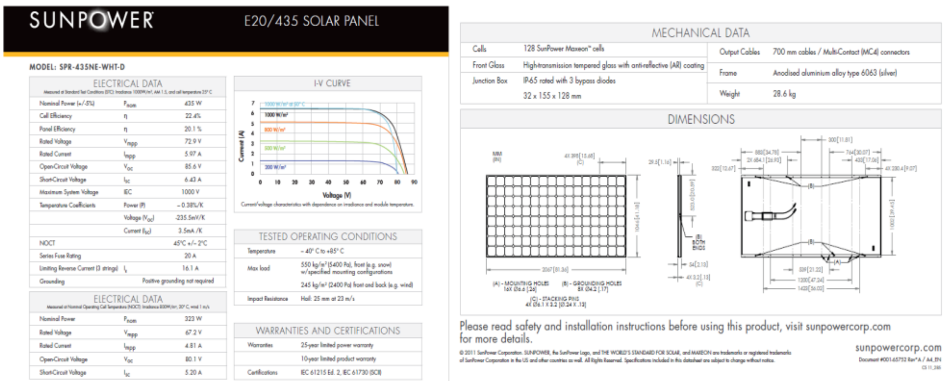
APPENDIX A.



MODELIRANJE PROJEKTA SAMOSTALNIH SOLARNIH FOTONAPONSKIH SISTEMA ZA TROSOBNI OBJEKAT U GRADU UMUAHIA, DRŽAVA ABIA, NIGERIJA

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Apstrakt: Ova studija ispituje raspored, rad i izvodljivost samostalnog solarnog fotonaponskog (PV-Solar Photovoltaic) sistema za trosobni objekat-bungalov u gradu Umuahi, država Abia, Nigerija.
Solarni panel, regulator punjenja, baterija i invertor su glavni elementi dizajna solarnog fotonaponskog sistema. Utvrđeno je da je dnevna potrošnja energije bila 21 kWh, što je prevedeno u ukupnu snagu od 2,4 kW. Za SPV system (Stand-alone Solar Photovoltaic) je izabrano dvadeset (20) solarnih panela kapaciteta 435 W. Stvarni napon kod solarnog regulatora punjenja je 102 A, a njegova snaga 8,7 kW, prema SPV (Stand-alone Solar Photovoltaic) dizajnu.
Predviđeno je da solarnom sistemu treba dvanaest (12) baterija, a za SPV sistem je izabrana jedna (1) baterija kapaciteta 250 Ah. Utvđeno je da ulazna snaga invertora ima vrednost od 3,2 kVA.
Maksimalna jednosmerna struja (AC) i napon su 192 A i 24 V, respektivno, a naizmenična struja (DC) i napon za SPV sistem bili su 11 A i 230 V, respektivno.
Najveći broj solarnih panela bio je postavljen u mesecu Avgustu, kada je sunčeva energija bila najmanjih vrednosti.
Procenjena stvarna dnevna proizvodnja električne energije (21 kWh) i prosečna mesečna proizvodnja energije (630 kWh) su bile ispod mesečnog minimuma (1620 kWh) i maksimalne teorijske proizvodnje energije (5980 kWh). Solarna fotonaponska energija zadovoljava energetske potrebe ispitivanog trosobnog objekta.
Odnos solarnih performansi je na nivou od 85,5%.

Ključne reči: *Dizajn; fotonaponski sistem solarne energije; modul, kontroler punjenja, baterija; inverter; izlazna snaga; sunčevo zračenje; odnos performansi.* [2]

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DEVELOPMENT OF AN INDIRECT SOLAR DRYER FOR THIN LAYER DRYING OF RED AND WHITE ONIONS

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Abstract: A solar dryer is intended to address the limits of natural sun drying, such as exposure to direct sunlight, risk of rodents and pest, lack of sufficient monitoring, and the increasing expense of the drier. The solar dryer is made up of an integrated solar collector and a drying chamber which is constrained by a rack of three cloth (net) trays. The solar dryer has the following dimensions: a stand that is 60 cm in height, a width of 30 cm, a length of 40 cm, and a height of 60 cm. Therefore, after drying the onion samples, the proximate analysis results show the difference between the fresh and dried samples for the two varieties of onion considered in this study.

Key words*: Solar dryer, Onions, Proximate, drying, moisture.*

INTRODUCTION

One of the most consumed vegetables worldwide is onion (*Allium cepa L.)* which is consumed either as fresh or dried product and has medicinal applications. It includes vitamin B as well as traces of calcium, iron, and vitamin C, [1,2].

Onions have a relatively high heat energy value compared to other fresh vegetables, a moderate level of protein, and are high in calcium and riboflavin [2].

Onions are largely used as a flavoring component in many nations [1]. They include a variety of healthy chemical constituents, including organic acids, vitamins, phenolic compounds, fiber, and other antioxidants [3].

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Gallic acid and quercetin are significant compounds that contains antioxidant, antiallergic, antimicrobial, anti-inflammatory, anti-hyperglycemic and anti-lipid peroxidative properties [4,5].

The average daily intake of phenolic compounds is around 1756 mg, which may be achieved in part by consuming onions [6]. Changes in temperature have a significant impact on phenolic compounds; Therefore, the right postharvest treatments and onion storage are required to preserve these chemicals. One post-harvest process for onions is drying; during this procedure, heat is used to eliminate any moisture content [,7]. Drying can lower the high moisture content of harvested onions, which is >80% [10], to 10% or less, extending their storage life. However, prolonged drying might reduce the phenolic compounds' stability and cause the antioxidant chemicals in onions to degrade [8]. Furthermore, the introduction of too much heat during drying might result in a reduction in vitamin C, color, and other components [9].

Dehydrating food products by drying entails removing moisture from the food to extend its shelf life by limiting bacterial development. Sun drying (putting the crops out in the sun to dry) is cheaper, but the finished product is of inferior quality because of dust, insects, birds, dogs, and rain contamination [10,11]. Additionally, direct exposure to UV radiation causes a loss of vitamins, minerals, and unattractive color changes, and it takes a longer time to dry [12,13] showed that when sun drying and solar dryers were compared, the former produced superior drying temperatures, lower product moisture content, lower relative humidity, and reduced spoilage. When compared to open-air drying, [14] have demonstrated that solar dryers produce dried commodities of higher quality and cut down on drying time by about 20%. According to [15,16,17], there are numerous variations in solar dryer sizes and designs, such as tunnel dryers, hybrid dryers, dryers that are oriented both horizontally and vertically, multi-pass dryers, and active and passive dryers.

Literatures affirm that solar dryers using forced convection are more effective than those with natural convection [11,18,19]. Additionally, forced convection solar dryers may dry products more quickly than natural convection solar dryers, and the finished goods produced by forced convection drying are of higher quality. In this Paper, a low-cost indirect mode solar dryer was designed and developed using environmentally friendly and locally accessible materials. The performance evaluation of the solar dryer was carried out to include proximate analysis, moisture removal rate and dryer efficiency for the red and white onions was carried out.

MATERIAL AND METHODS

Preparation of materials

The onions (red and white onions) were purchased at Ofa market in Ilorin, Nigeria. The samples brought to the lab preparation which include cleaning and washing to remove dirt and particles for the onions as seen in fig.1 below, to be weighed appropriately to know the accurate kilo weighed.

The onions were placed on a stainless-steel tray for slicing, before slicing the outside part of the onion was piled with a knife; the onions were sliced with a knife in diameter of 3mm and 5mm and the sliced onions were spread on the stainless-steel tray then load into the dryer.

a. Red Onion b. White Onion c. Slicing of onions d. Onions Slices

Figure 1. Image of Onion sample preparation

Design procedure

The design of the indirect solar dryer took into consideration different design criteria and parameters. These design parameters include environmental condition of experimental location, amount of moisture to be removed, drying temperature, heat energy requirement, sizing and orientation of the solar collector and determination of airflow requirement.

(a) Environmental condition of the experimental location

The solar dryer was fabricated and evaluated in Ilorin, Kwara State, Nigeria. Records gotten from the Meteorological Department of Ilorin International Airport (MDIIA) showed that the average solar irradiation for Ilorin was 340.8 W/m^2. The ambient temperature, T_a for the place of drying test was 25^{0}C with relative humidity of 67%.

(b) Amount of moisture to be removed

The quantity of onions sample to be dried is 4kg which is the volumetric capacity of the dryer. The formula to calculate the total amount of moisture removed M_w is given by [20,21] as in eq. 1 below:

$$M_w = \frac{W_{m}(M_i - M_f)}{I - M_f} \quad \text{………………………(1)}$$

Where,
M_w is the amount of moisture removed;
M_i is the initial moisture constant on wet basis;
M_f is the final moisture content on wet basis

(c) Drying temperature

ADOGA [20], recommended drying temperatures of fruits and vegetables to be between 40-45 ^{0}C. Higher temperature may cause browning of sugar of many fruit products when drying. Hence, for designing the dryer, average drying temperature, T_d of 45^{0}C was considered.

(d) Heat energy required to remove water

The heat required to remove water from a produce was calculated using the formula provided by [21]. This is given as seen in eq. 2 below:

$$Q_1 = M_w \times C_p \times D_T \quad \text{…………………………………..(2)}$$

Where,
C_p is the specific heat capacity of the produce (in kg^{0}C) and
D_T = Td-Ta is temperature change (in ^{0}C).

Specific heat capacity of a food material can be determined using the following equation as seen in eq.3 below

$$C_p = M_c \times M_p \times M_f \times M_a \times M_i \qquad \text{……………………..……(3)}$$

Where,
M_c; M_p ; M_a; M_w; M_i is mass of fraction of carbohydrate, protein, ash, water, ice respectively.

The second stage is evaporating the moisture from the produce. As water start to evaporate after the produce is warmed up to the drying temperature, heat required to evaporate is giving by eq. 4 below

$$Q_2 = M_w \times L \qquad \text{…………………………..……(4)}$$

L = h_g – h_f, the latent heat of vaporization.

The values for h_g (enthalpy of a water vapour) and h_f (enthalpy of water as liquid) at the drying temperature were obtained from psychometric chart.

(e) Sizing the collector
The daily average isolation of Ilorin (where the experiment was carried out) is taken to be 15.48 MJ/m^2/day [22]. Struckman [23] presented the efficiency of a typical flat-plate collector be between 25-45%. The collector efficiency was influenced by factors such as temperature, airflow rate, type of transparent material, absorber plate and insulation used. To achieve an optimal design, average value of collector efficiency of 35% was considered as a design parameter. As a result, expected energy production by the collector was 10.84 MJ/m^2/day for two days, and the collector area was 0.82 m^2. Barki et al. [24] suggested that the length to width ratio of a solar collector to be 1: 2. Considering the ratio to be 1:2 for this design, the length and width of the collector were 130 cm and 60 cm, respectively.

(f) Orientation and tilt angle of solar collector
The flat plate solar collector was tilted and oriented in a way that it received maximum radiation. Optimal tilt angle varies according to the season. Generally, optimum angle of tilt is equal to the degree of latitude of the site [25]. In this design, the test location was in Ilorin (latitude 8^{0}30̓N), a collector tilt angle of 10^0 was considered.

Air flow requirement in the drying chamber
Author et al. [26] recommended the range for air velocity to be between 0.51 m/s to 5.08 m/s. In addition, the depth of the air channel should be 1/15 to 1/20 of the length of collector.

Taking the average factor of the depth of the air channel (0.058) as recommended the depth of air channel was 7.54 cm. The vent area which was estimated as a product of the width of collector and air gap (6.18 m^2).

Determination of Proximate Composition of Onion Samples

Proximate Composition (Total Moisture Content, Crude Protein, Crude Fat, Crude Fiber, Ash Content,) of the two varieties of raw onions were determined by the following methods

Moisture content determination

Fresh onion samples of 30 g were placed in pre-weighed aluminum weighing dishes and according to the America Dehydration of Onions and Garlic Association [20] temperature of 70 ^{0}C for 6 hrs at 26.1 Hg vacuum in Thelco 29 vacuum oven (precision scientific, Chicago, IL). Moisture contents were estimated on dry basis using the following formula developed by Adoga [20] to obtain the initial moisture content as seen in eq. 5 below.

$$M_c(\%db) = \frac{w_{i-w_f \times 100}}{w_f} \quad \text{.............................(5)}$$

Where,
W_i was the initial weight of the sample and
W_f was the final weight of the sample

Determination of Crude Protein

The onion sample was tested for crude protein content according to the Kjeldahl's method as described in AOAC [27], which involved protein digestion and distillation. About 2.0 g of the sample was weighed into an ash less filter paper and put into a 250 ml Kjeldahl flask. Then, 1 g of digestion mixture (as catalyst) and 15-20 ml of 98 % conc. Sulfuric acid were added. The whole mixture was subjected to heating in the digestion chamber until transparent residue contents were obtained. Then, it was allowed to cool. After cooling, the digest was transferred into a 100 ml volumetric flask and made up to the mark with distilled water and then distilled using Markham distillation apparatus. The digest in the condenser was steamed through until enough ammonium sulphate was collected. The solution in the receiving flask was titrated with 0.063 N hydrochloric acid up to a purple end point. After titration, the % nitrogen was calculated using the formula as seen in equation 6 below:

$$\%Nitrogren = (V_s - V_B) \times M\ acid \times 0.01401 \times 100W \quad \text{................(6)}$$

Where,
Vs is the Volume (ml) of acid required to titrate sample;
VB is the Volume (ml) of acid required to titrate the blank;
M acid is the Molarity of acid;
W is the Weight of sample (g).
Then, percentage crude protein in the sample was calculated from the % Nitrogen as % crude protein = % N x F, where, F (conversion factor), is equivalent to 6.25, [28].

Determination of Crude Fat, Crude Fibre and Ash Content

The crude fat was estimated in the onion sample was determined using Soxhlet extraction for 24 hours.

The % fat in the sample was calculated using the formula as seen in equation 7.

$$Fat(\%) = \left(\frac{Weight\ of\ fat}{Weight\ of\ original\ sample}\right) \times 100 \qquad \text{.........................(7)}$$

The crude fibre was estimated using 2 g fat free sample of onion which was taken into a fiber flask and 100 ml of 0.255 N H_2SO_4 was added. The residue was washed with 50 ml of hot water twice on the sieve cloth before it was finally transferred in the pre-weighted crucible. The crucible with residue was oven dried at 105 ^oC overnight to drive off moisture. The oven dried crucible containing the residue was cooled in a desiccator and latter weighted (W1) for ashing at 550 ^oC for 4 hours [28]. The crucible containing white and grey ash (free of carbonaceous material) was cooled in a desiccator and weighted to obtain W2. The % of crude fiber was calculated as follows as shown in equation 8 while the % ash content in the onion sample was calculated as follows in seen equation 9

$$Fibre(\%) = \left[\left(\frac{W1-W2}{weight\ of\ sample}\right) \times 100\right] \qquad \text{...............................(8)}$$

$$Ash(\%) = \left(\frac{weight\ of\ ash}{weight\ of\ sample\ taken}\right) \times 100 \qquad \text{.....................................(9)}$$

Side view of the dryer | Front view of the dryer | Top view of the dryer | Inner view of the dryer

Figure 2. Pictorial representation of the dryer

Drying of Onion Samples

Prior to drying, the onions were weighed at 1.7 kg and chopped into 3 and 5 mm diameters. After the proximate analysis test was completed, the sliced onions were taken to the dryer's location. The drying chamber door was opened, and the sliced onions on the stainless-steel tray were moved to the mesh plate inside the drying chamber. The sliced onions on the mesh try were evenly distributed, as shown in figure 3. The door to the drying chamber was closed once the Red and White sliced onions had been arranged on the mesh tray within.

Pouring of onions in trays | Arranging of red onions | Arranging of white onions | Drying

Figure 3. Drying procedure

RESULTS AND DISCUSSION

Results of the proximate composition in studied sample materials are shown in Table 1. The proximate analysis of the two varieties of *Allium cepa* L. revealed that the moisture contents, dries from 84 % to 14.13% in the red onion, while for White onion it dries from 85 % to 14.54%. There was a substantial difference in the fat, Ash, fibre, protein contents of both varieties, with the white Onion variety having a higher value compared to the red onion. The interaction effect of variety and moisture content was significant as shown in the proximate analysis result. The change increased with an increase in drying temperature, but the increase was significantly different among onion varieties.

Table 1. Proximate composition of two varieties of onions

Parameter	Sample			
	Red Onion		White Onion	
	Fresh	Dried	Fresh	Dried
Moisture content	84%	14.13%	85%	14.54%
Fat	0.6%	1.02%	0.5%	1.10%
Ash	0.7%	1.51%	0.8%	1.60%
Fibre	1.4%	1.95%	1.3%	2.10%
Protein	0.8%	1.54%	0.9%	1.62%

The white variety of Allium cepa L. has the highest moisture content (14.54%) of the two varieties examined in proximate analysis. Given their susceptibility to deterioration, the high moisture content of both *Allium cepa* L. types indicates that proper care is required for their preservation. Their susceptibility to microbial infections is increased. The body benefits from the high water content as it doesn't have to expend as much of its own water to digest them. This indicates that the body can assimilate all the nutrients much faster and with fewer energy and resources throughout the digestion process. Therefore, the digestive tract is under less pressure [29]. The level of protein in the two varieties of *Allium cepa* L. was not too high; however, the protein content of the white onion variety (1.62 %) was higher than that of the red onion variety (1.54 %). The higher protein contents of white onion studied, indicates that its intake can contribute to the formation of hormones which controls a variety of body functions such as growth, repair, and maintenance (replacement of wear and tear of tissues) foody. In addition, it may be useful as a preferred option to animal proteins for diabetics as the later tend to be high in saturated fats. This confirms that onion is an energy giving food.

The presence of crude fiber in the diet is necessary for digestion and for elimination of wastes. The contraction of muscular walls of the digestive tract is stimulated by fiber, thus counteracting constipation [30]. In addition, it decreases the absorption of cholesterol from the gut in addition to delaying the digestion and conversion of starch to simple sugars, an important factor in the management of diabetes. It may reduce cerium cholesterol levels too. Crude fiber also functions in the protection against cardiovascular disease, colorectal cancer, and obesity. Thus, the high percentage fiber contents in the White variety of onion (2.10 %) makes it more effective and useful than the red one (1.95 %) in the management of diabetes mellitus, colorectal cancers, and weight reduction in obsessed individuals, and this is the most significant finding in this present study. The study of ash content is very important to the extent that it provides an insight into the nutritionally important inorganic mineral elements, which are presented in Table 1. It was reported that the ash content of a food sample gives an idea of the mineral elements present in the food sample [31]. In the present study, both the varieties exhibited low level of ash content. Yet, white variety of *Allium cepa* L. could be promising sources of essential or non – essential mineral elements as it holds higher level of ash content (1.60%) than that of red onion (1.51 %). The effect of excess intake of crude fat has some well-established health implications especially for the overweight. The consumption of excess amounts of fats has been recognized as the most important dietary factor aiding increased level of cholesterol. Besides the cholesterol implications due to high fat intake, obesity is a factor in the causation of disease [31]. In this regard, red variety of *Allium cepa* L. could be said to be better preferred as it may reduce the risk of coronary heart disease and lower the risk of hypertension due to its lower crude fat content of about 1.51%

Table 2. Drying Properties

Properties	Value
Heat energy required to remove water	
M_i	0.84 kg
W_m	4 kg
M_f	0.14 kg
M_w	3.26 kg
C_p	11.97 KJ/kg^{0}C
D_T	20^{0}C
Q_1	957.56 KJ
h_g	2583 KJ/Kg
h_f	188 KJ/Kg
L	2395 KJ/Kg
Q_2	7807.7 KJ
Q	8765.3 KJ
Airflow requirement in the drying chamber	
Volume flow rate	0.02331 m^3/s
Mass Flow rate	0.02080 kg/s

This mass flow rate value lies between the ranges of 0.02-0.9 kg/s, as recommended by [33] for natural convection dryers. The results from the table 2 indicate that drying has significant effect on the quality of two varieties of onion, namely, red onion and White onion. Generally drying is simply defined as the removal of moisture content from food.

Moisture content after drying is one of the important parameters used to estimate the performance of the solar dryer. The moisture content of the red and white onion decreases after drying while the fat, ash, fibre, and protein of the red and white onion increase after drying. The drying time for red onion was 12 hours and the drying time of white onion was 12 hours 45 minutes. The dried red onion and white onion was placed in a glass cylinder for packaging.

CONCLUSIONS

The moisture content reduced from 84% to 14.13%, while in fresh white onion, the moisture content reduced from 85% to 14.45% after drying. The fat in the red onion increased from 0.6% to 1.2% after drying, the fat in white onion increased from 0.5% to 1.10% after drying. The ash in red onion increased from 0.7% to 1.51% after drying, the ash in white onion increased from 0.8% to 1.6o% after drying. The fibre in the red onion increased from 1.4% to 1.95% after drying, the fibre in white onion increased from 1.3% to 2.10% after drying. The protein in the red onion increases from 0.8% to 1.54% after drying, the protein in white onion increased from 0.9% to 1.62% after drying. The moisture content of the red and white onions decreases after drying while the fat, ash, fibre, and protein all decreases after drying.

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RAZVOJ INDIREKTNE SOLARNE SUŠARE ZA SUŠENJE CRVENOG I BELOG LUKA U TANKIM SLOJEVIMA

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Apstrakt: Solarna sušara je namenjena rešavanju ograničenja/problema prirodnog sušenja na suncu, u odnosu na izlaganje direktnoj sunčevoj svetlosti, ili rizika od prisustva glodara i štetočina, ili nedostatka dovoljnog praćenja procesa, ili sve većih troškova klasičnih modela sušara.

Solarna sušara se sastoji od integrisanog solarnog kolektora i komore za sušenje koja je ograničena stalkom od tri platnene (mrežaste) posude. Solarna sušara ima dimenzije: postolje visine 60 cm, širine 30 cm, dužine 40 cm i visine 60 cm.

Zato, nakon sušenja tankih uzoraka luka, rezultati neposredne analize, pokazuju razliku između svežih i sušenih uzoraka za dve sorte luka koje se razmatraju u ovoj studiji.

Ključne reči: *Solarna sušara, luk, neposredno, sušenje, vlaga.*

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IMPACT OF FLOODING ON LIVELIHOODS AND MITIGATION STRATEGIES IN SELECTED COASTAL COMMUNITIES IN AKWA IBOM STATE

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Abstract: In this study, impact of flooding on livelihoods in Obianga, Emereoke, Inua Eyet Ikot and Iwuo Okpom Opulom Communities of Eastern Obolo and Ibeno Local Government Areas, Akwa Ibom State was assessed. The study adopted cross-sectional survey with sample population comprised of inhabitants in the coastal communities which was determined using purposive and random sampling techniques via by Godden formula. Data were collected from primary (researcher-made questionnaire) and secondary sources (archives, agricultural / meteorological stations and United States Geological Surveys). Data collected comprised of participants' demographic characteristics, their perspective on the degree of flood tendency in their communities, digital elevation model (DEM) output of flood tendencies using climatic data variables between 2010 to 2019, major livelihood activities, their vulnerabilities to flooding and coping strategies to mitigate the impact of flooding on livelihoods. Ethical issues were upheld before copies of questionnaire were administered and collected back. Data were analyzed using geographical information (GIS) techniques, ArcGis software 10.3 and Microsoft Excel 2016. A total of 287 respondents were interviewed.

The demographic characteristics revealed that more household heads were men, majority were young people, whereas the singles were migrants. Household earning was negligible with an average size of five people. Iwuo Owo Opulom Community had more flooding destructive tendency than Obianga.

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Emereoke Community may be subjected to flooding overtime whereas Inua Eyet Ikot Community may gradually become flood risk site if neglected as assessed participants. Three (3) main livelihoods were crop production, fishing and trading. Fishing, crop production and trading livelihoods in Ibeno district (Inua Eyet Ikot Community) had the highest vulnerability scores of 0.225, 0.178 and 0.165 respectively. These imply that Inua Eyet Ikot Community is the most vulnerable to flooding than the others. Local coping strategies to mitigate flood impact comprised of physical assets, social networks, credit facilities, insurance and government waivers and alternative livelihoods. It was suggested that drainage systems should be constructed and precise flood warning system should be amounted particularly in the flood prone areas through various agencies and NGOs.

Keywords: *Flooding, Livelihoods, Coastal Communities, Mitigation strategies*

INTRODUCTION

Environmental catastrophes are not only resulted from natural drivers but have also been fostered by human interventions [1]. World population has surpassed 7.7 billion people with probability to reach nine billion by 2030 [2]. Meaningfully, 44% of the world population, lived within 150 km of the world' coastlines. The mean population density in these coastal areas is expected to rise to 80 people / km^2. In addition, coastal populations are increasing faster than those of inland populations in many countries. Globally, it is well known that a cumulative share of the populace and economic assets lie in areas prone to riverine and coastal flood menace. These trends have geometrically observed [3]. Majority of the inhabitants in coastal region, for example, in Nigeria, are associated with either agriculture or fishing or both, which are extremely dependent on the natural ecosystems. Unfortunately, livelihoods in these regions have progressively decreased pushing farmers and fishermen to look for other livelihoods over the past decades [4]. Factors responsible for heavy flood hazard are numerous and correlated. It was revealed that the possible climate variations are anticipated to cause an increase in the frequency, and rainfall intensity, which may result in a more extensive and fatal natural catastrophe [5]. Evidence has shown that the influence of climate variation on livelihoods is probable to be experienced by smallholder farmers who is deficient in essential means for adaptation [6]. Ionita and Nagavciuc [7] reported that some scientific evidence of an upsurge in average precipitation and precipitation intensity, which suggests that extreme flood events might become more recurrent. Flooding has been observed to worsen poverty levels and vice versa. However, community resilience and ability to deal with both flooding and poverty have been established to be inefficient in most communities. For instance, in the just year 2010 alone, floods had contributed 82.6% of all catastrophes that happened in the African continent, an increase from 66.5% that was observed in 2009, [8].

Africa's poverty would persist and possible be worsen as proved by the noticeable low life expectancy, low per capita income, disease and hunger [9]. As such, upsurged poverty levels in Africa have forced people to live under vulnerable situations [10]. Again, impact of flood resulting from sea level rise on livelihoods would continue to be aggravated because coastal areas are usually highly populated with many economic opportunities.

High population density along coastal regions is motivated by the fertile land, transport opportunities and easy access to sea food, etc. [11] and coastal areas are highly productive areas [12]. Rises in sea levels had negatively impacted several coastal regions of the world, especially in developing nations [13]. In Nigeria, more people are living in unhealthy regions due to poverty and poor governance, majorly as impacts of natural calamities, and its consequences [14]. A careful looked at several studies related to flooding along coastal regions [15, 16, 17, 18, 19, 20, 21, 22, 23] only produced a link between flooding and livelihood and majority focused on the poor rural inhabitants and not on their sources of livelihood. Some previous researches centered on geographical information system and remote sensing, cross sectional surveys and use of secondary data. This present study used the mixed methods of Geographical Information System (GIS) and survey method to obtain information. Therefore, more awareness had to be created on the impact of flooding on livelihoods and mitigation strategies in selected coastal communities: Iwu Owo Opulom, Inua Eyet Ikot, Emeroeke and Obianga in Ibeno and Eastern Obolo LGAs respectively, in Akwa Ibom State. The study would establish underlying causes of vulnerability of people in these communities and would give key inputs in designing of sustainable mitigation measures to minimize the impacts of coastal flooding in Akwa Ibom State.

METHODOLOGY

Study Area

The study areas were some coastal communities (Obianga, Emereoke, Inua Eyet Ikot and Iwuo Okpom Opulom) found in Eastern Obolo and Ibeno Local Government Area (LGA) of Akwa Ibom State (AKS), Nigeria. However, Eastern Obolo LGA lies between latitudes 4°28' and 4°53' and longitudes 7°50' and 7° 55' East whereas Ibeno LGA lies between 4°33′N and 8°4′E. The major occupation of the inhabitants is fishing. Hence, most of them are fishermen. However, crop production and inconsequential trading are also found, [24].

Fig. 1. The location of the study, [24].

Research Design, Sampling Method, Population and Sample Size

Research design adopted was cross-sectional survey. The sampling techniques used were purposive and random sampling techniques. The population consisted of inhabitants in the coastal communities in Akwa Ibom State. The sample size (n) was found using Z as 1.96 for 95% confidence level, P as % population [25] and C as 0.05 for confidence interval in Godden formula given in Equation (1):

$$n = \frac{Z^2 . P . (1-P)}{C^2} \quad (1)$$

Sources of Data and Data Collation Modes

The study data were obtained from both primary and secondary sources. A researcher-made questionnaire was used. It contained either closed-ended or open-ended questions or both. The secondary data were gathered from archives, agricultural / meteorological stations [25, 26].

However, data collection modes were as follows:

(a) Demographic Characteristics

The respondents were requested to provide their sex, age range, income and marital status and house hold size;

(b) Flood Status in the Study Areas

- The respondents were to access the degree of flood tendency in their communities;
- The researcher used digital elevation model (DEM) of 90 m × 90 m resolution from United States Geological Surveys, USGS, to collect climatic data variables, rainfall pattern and temperature data between 2010 to 2019 from Maritime Academy of Nigeria, NiMet office, Akwa Ibom Airport, and Accuweather Centre in assessing flood risk sites, its nature and possible impact on livelihood of the inhabitants.

(c) Livelihood Activities and their Vulnerabilities to Flooding

The major livelihood activities in the study areas were established. Their vulnerabilities to flooding from the household survey [27] were computed with respect to the following five (5) components as: (i) socio-economic variables (SDP) which had 5 subcomponents (dependency ratio, % female-headed households, average age of female head of household, % households head not attended school, % households with orphans), (ii) social Network (SN) which had 3 subcomponents (average receive: give ratio, average borrow: lend money ratio, % households that had not gone to their local government for assistance in the past 12 months), (iii) livelihood strategies (LS) had 3 subcomponents (% households with family member working in a different community, % households dependent solely on a single livelihoods such as fishing, artisan, trading, crop farming as a source of income, average rural livelihood diversification index), and (iv) climatic factors and natural disaster events (CN) had 3 subcomponents (mean standard deviation of monthly average of maximum daily temperature since 2010, mean standard deviation of monthly average precipitation since 2010, % households with an injury or death as a result of flood since 2010).

However, each component was measured on a different scale and standardized as an index (Index_{Sd}) using S_d as the observed sub-component indicator for district *d,* S_{min} and S_{max} as minimum and maximum values, respectively in Equation 2 [27].

$$\mathrm{Index}_{Sd} = \frac{S_d - S_{min}}{S_{max} - S_{min}} \quad .. \quad (2)$$

Then, the sub-component indicators (Index_{Sdd}), indexed by *i*, were averaged using *n* as number of sub-components in each major component in Equation 3 to obtain the index of each major component (M_d) as:

$$M_d = \sum_{n=i}^{n} \left(\frac{\mathrm{Index}_{Sdd}}{n}\right) \quad .. \quad (3)$$

Once the values for each major component for a region were calculated, they were averaged to obtain the district-level LVI (LVI_d) using W_{mi} as the weights of each major component in Equation 4 as:

$$LVI_d = \frac{\sum_{i=1}^{4} (W_{mi} \cdot M_{di})}{\sum_{i=1}^{4} (W_{mi})} \quad .. \quad (4)$$

Thereafter, the major components were first combined according to three categories namely: exposure, adaptation capacity and sensitivity using Equation 5 to obtain IPCC-defined contributing factor (exposure, sensitivity, or adaptation capacity) $[CF_d]$ for district, d.

$$CF_d = \frac{\sum_{i=1}^{n} (W_{mi} \cdot M_{di})}{\sum_{i=1}^{n} (W_{mi})} \quad .. \quad (5)$$

Once exposure, sensitivity, and adaptation capacity were calculated, the three contributing factors were combined using Equation 6 as:

$$LVI - IPCC_d = (e_d - a_d) \times S_d \quad (6)$$

Where,
$LVI - IPCC_d$ is the LVI for district,
d expressed using the IPCC vulnerability framework;
e_d is the calculated exposure score for district,
d (equivalent to the natural disaster and climate major component),
a_d is the calculated adaptive capacity score for district,
d (weighted average of the socio-demographic profile and social networks major components), and
S_d is the calculated sensitivity score for district, d (weighted average of the livelihood strategies major components).

Besides, the LVI-IPCC computation for the study was scaled from 0.01− 0.049 (very low vulnerability), 0.05− 0.099 (low vulnerability), 0.10− 0.149 (moderate vulnerability), 0.15− 0.199 (high vulnerability), and 0.20−0.249 (very high vulnerability) (Yusuf and Francisco, 2009; IPCC 2001). The implication is that a higher net value indicates higher vulnerability and lower net value indicates lesser livelihood vulnerability to flooding.

(d) Coping Strategies to Mitigate the Impact of Flooding on Livelihoods

The household heads were asked to indicate various coping strategies practiced to build their resilience and also mitigate the impact of flood events on their livelihoods based on the following options in the questionnaire: (I) ownership of fishing canoe, boats and nets, (II) construction of drainage/sand bags, (III) planting of shrubs/trees/cover crop, (IV) strength of social networks, (V) Form local groups/belong to cooperative society, (IV) use insurance/credit facility, (VII) availability/access to early warning system, (VIII) alternative livelihoods, (IX) international donation/supports and (X) remittance from family members.

Ethical Issues, Instrument Administration

In taking care of ethical issues, participants were informed of the purpose of the study before copies of questionnaire were administered by trained research assistants. They were also asked not to write their names on questionnaire, and feel to response to any item they desired. Key informant interview (KII) was conducted using two village heads, community leader, youth leaders and a church leader in a local dialect which was later translated into English language. Besides, copies of questionnaires were randomly administered to household heads and collected back for analysis. Again, in-depth discussion and interview were conducted on focus group who were affected by flood within the selected communities.

Method of Data Analysis

The analytical techniques included GIS techniques, descriptive and multivariate statistical analysis. The data obtained from the questionnaire were subjected to descriptive and multivariate analysis. Digital elevation model was obtained and analyzed using ArcGis software 10.3 in analyzing the topography of the study area for flood risk assessment

RESULT AND DISCUSSION

(a) Demographic Characteristics of the Respondents

The demographic characteristics of the respondents (household heads) such as sex, age range, income, marital status and household size are presented in Figures 2, 3, and Tables 1 and 2. There were more male respondents than females. About 61.7% were males, while 38.3% were females. However, a total of 287 respondents were interviewed.

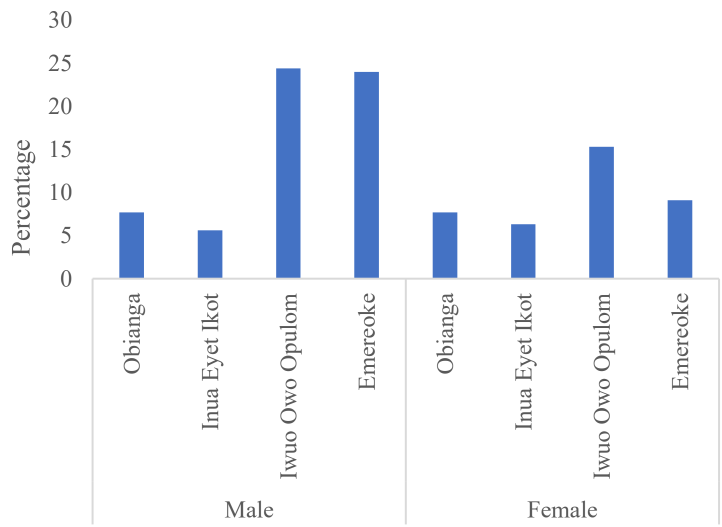


Fig. 2. Sex composition of household heads in each location

Table 1. Age range of the respondents

Age Range (Years)	Location	Percent (%)
<18	Obianga	4.9
20-39		5.6
40-59		3.9
>60		1.4
<18	Inua Eyet Ikot	5.6
20-39		3.8
40-59		1.0
>60		1.4
<18	Iwuo Owo Opulom	8.0
20-39		17.1
40-59		14.6
>60		0.3
<18	Emereoke	4.1
20-39		21.0
40-59		4.5
>60		3.4

From the Table 1, the majority of the household heads were between 20-39 years (47.5%), mostly in Iwuo Owo Opulom (17.1%). Those between the ages of 40-59 years were 24%, while 22.6% of the respondents were less than 18 years. The study further established that 6.2% of the respondents were more than 60 years.

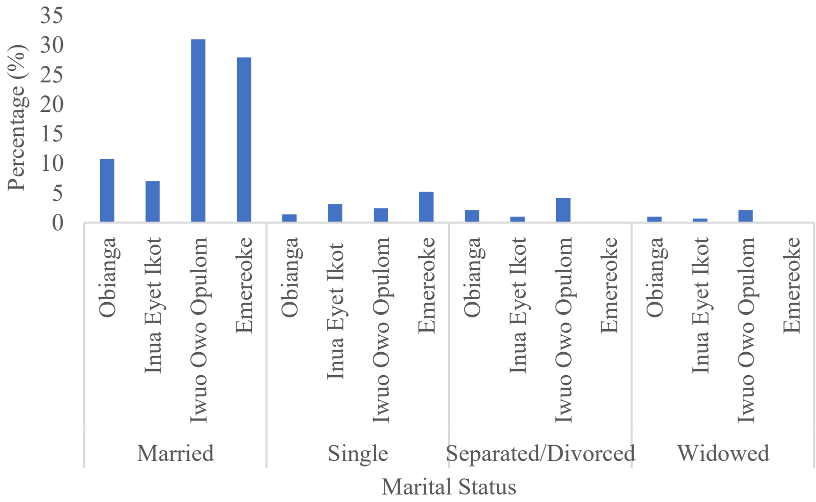


Fig. 3. Marital status of household heads

From the Figure 3, about 76.7% of the respondents were married whereas 12.2% were single. The separated/ divorced and widowed were 7.3% and 3.8% respectively.

Table 2. Income level of the respondents

Income Level (Naira or N)	Location	Percent (%)
2,000-5,000	Obianga	2.1
	Inua Eyet Ikot	1.0
	Iwuo Owo Opulom	7.7
	Emereoke	4.9
5,001-10,000	Obianga	3.1
	Inua Eyet Ikot	1.0
	Iwuo Owo Opulom	4.5
	Emereoke	4.5
10,001-15,000	Obianga	3.5
	Inua Eyet Ikot	2.1
	Iwuo Owo Opulom	8.7
	Emereoke	9.4
15,001-25,000	Obianga	4.2
	Inua Eyet Ikot	2.8
	Iwuo Owo Opulom	4.5
	Emereoke	10.1
> 25,000	Obianga	2.4
	Inua Eyet Ikot	4.9
	Iwuo Owo Opulom	14.3
	Emereoke	4.2

Table 2 shows that 25.8% of the respondents earn more than N25,000 in a month with Iwuo Owo Opulom (14.3%) having the highest proportion compared to Obianga (2.4%). Again 23.7% and 21.6% of the respondents earn between N10,001 - N15,000 and N15,001 – N25,0000 per month respectively.
Furthermore, the range: N2,000 – N5,000 and N5,001 – N10,000 per month were earned by 15.7% and 13.1% of the respondents accordingly. Besides, the household size of the respondents is shown in Table 3.

Table 3. Household size of the respondents

Household Size	Location	Percent (%)
1-2	Obianga	1.0
	Inua Eyet Ikot	1.4
	Iwuo Owo Opulom	3.1
	Emereoke	6.2
3-5	Obianga	7.7
	Inua Eyet Ikot	3.1
	Iwuo Owo Opulom	19.2
	Emereoke	6.3
6-8	Obianga	5.9
	Inua Eyet Ikot	5.9
	Iwuo Owo Opulom	5.6
	Emereoke	17.4
9-10	Obianga	0.7
	Inua Eyet Ikot	1.0
	Iwuo Owo Opulom	5.6
	Emereoke	2.9
>10	Obianga	0.0
	Inua Eyet Ikot	0.3
	Iwuo Owo Opulom	6.3
	Emereoke	0.0

From Table 3, the study established that household with less than 3 members were 11.7% whereas 36.3% of the household had 3 - 5 members, and 34.8% had 6 - 8 members. Those with 9-10, and more than 10 members were 10.2% and 6.6% respectively.

(b) Flooding Status in the Communities by the Respondents

The flooding status as responded by the participants in Iwu Owo Opulom, Obianga, Emereoke and Inua Eyet Ikot communities are presented in Table 4. Iwuo Owo Opulom community had the highest flooding intensity (46%), followed by Emereoke (30%), next by Obianga (14%), and lastly, Inua Eyet Ikot with the lowest percentage (10 %).

Table 4. Flooding Status in the Communities

S/N	Communities	Percent (%)
1	Iwu Owo Opulom	46
2	Obianga	14
3	Emereoke	30
4	Inua Eyet Ikot	10
	Total	100

(c) Nature of Flooding by Digital Elevation Model (DEM)

Here, the flood risk sites in the study areas were captured using climatic data variables. Figure 4 shows the digital elevation model (DEM) of Eastern Obolo and Ibeno Local Government areas (Emeroke, Obianga, Inua Eyet Ikot and Iwuo Owo Opulom).

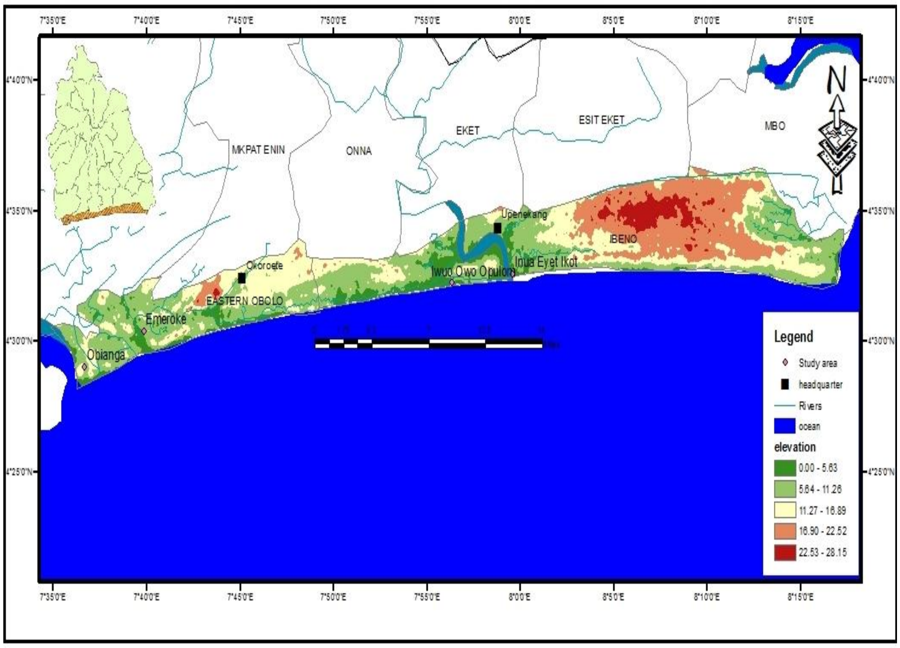


Fig. 4. DEM of Eastern Obolo and Ibeno LGAs

However, the rainfall data of the study areas between 2010 – 2019 is presented in Figure 5.

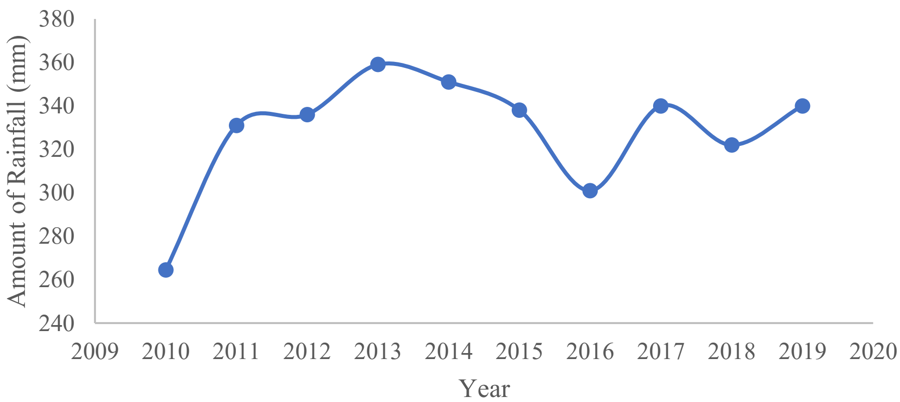


Fig. 5. Rainfall data of the study areas between 2010-2019.

As shown in Figure 5, in 2010, annual rainfall pattern rose steadily to a peak in 2013; and then dropped in 2016 before rose again between 2017 and 2019. The lowest amount of rainfall (264.4 mm) was in 2010 and the highest (364 mm) was seen in 2013. Another important climatic variable is temperature. Soils or areas that had experienced drought conditions for a certain period often get flooded during an episodic rainfall. However, the temperature data of the study areas between 2010-2019 is shown in Figure 6.

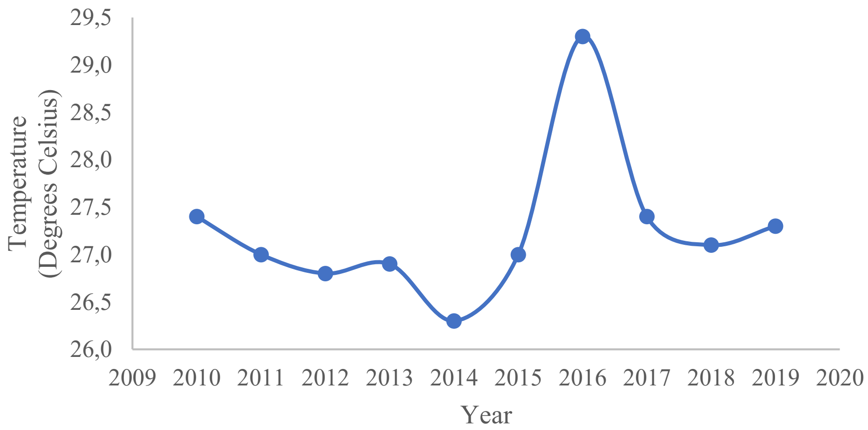


Fig. 6. Temperature data of the study areas between 2010-2019

As shown in Figure 6, temperature recorded a downward trend up to 2014 at 26°C as the lowest annual temperature and peaked drastically in 2016 (29°C) before further making a steep downward and steadily in 2019.

(d) Livelihood Activities and their Vulnerabilities to Flooding

The livelihood activities in the study areas are presented in Figure 7.

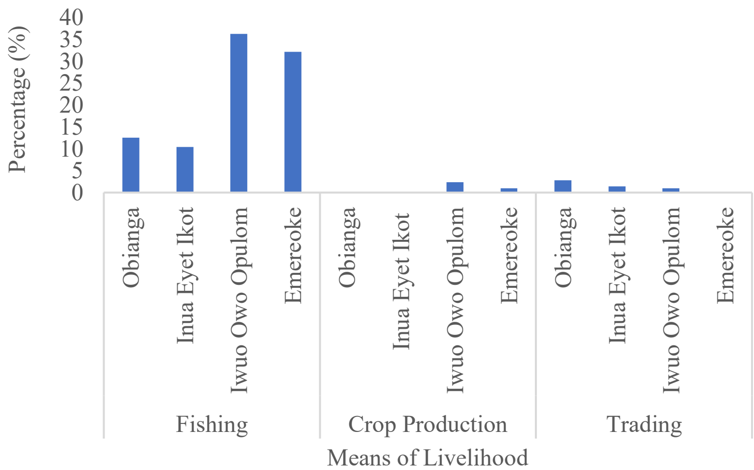


Fig. 7. Livelihood activities in the study area

Three (3) major livelihoods in the study areas were crop farming, fishing and trading. From Figure 7, 90.9% of the respondents depended on fishing as their major source of livelihood. This was followed by trading (5.6%) whereas 3.5% depended on crop production which is mostly subsistence farming. Nevertheless, Inua Eyet Ikot had highest (36.2%) in fish production. However, the major components of vulnerability were socio-demographic profile (SDP), social network (SN), livelihood strategies/adaptation (LS) and climate / natural disasters (CN). The summary of vulnerability of livelihood to flooding in the study areas is shown in Table 5.

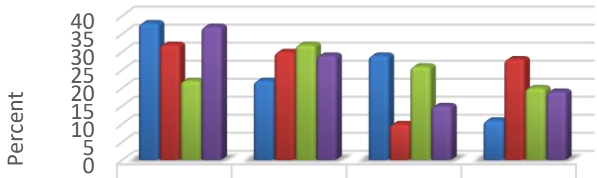
Table 5. Vulnerability of livelihood to flooding

Livelihood	Location	Vulnerability Score
Fishing	Obianga	0.137
	Emereoke	0.130
	Inua Eyet Ikot	0.225
	Iwuo Owo Opulom	0.174
Crop Production	Obianga	0.098
	Emereoke	0.072
	Inua Eyet Ikot	0.178
	Iwuo Owo Opulom	0.166
Trading	Obianga	0.013
	Emereoke	0.111
	Inua Eyet Ikot	0.165
	Iwuo Owo Opulom	0.115

In Table 5, vulnerability of fishing livelihood to flooding varied across the study areas. Fishing livelihood in Ibeno district were highly vulnerable to flooding. For instance, Inua Eyet Ikot Community had the highest vulnerability score (0.225), followed by Iwu Owo Opulom Community with vulnerability score of 0.174. In Eastern Obolo district, Obianga and Emereoke Communities with vulnerability scores of 0.137 and 0.130 respectively, were moderately susceptible to flooding. In term of vulnerability of trading to flooding, Inua Eyet and Iwu Owo Opulom Communities had high vulnerability scores of 0.165 and 0.115 respectively. In Eastern Obolo district, Obianga recorded a very low vulnerability score (0.013) compared to that of Emereoke community (0.111) which was moderately vulnerable to flooding. Although crop farming activity was negligible, in Eastern Obolo district, Emereoke and Obianga communities had low vulnerability scores of 0.072 and 0.098 respectively. Conversely, Iwu Owo Opulom and Inua Eyet Communities in Ibeno district had high vulnerability scores of 0.166 and 0.178 respectively.

(e) Local Coping Strategies to Mitigate Impact of Flooding on Livelihoods

The local coping strategies to mitigate flood impact on livelihoods in the study areas are presented in Figure 8. These comprise of physical assets, social networks, credit facilities, insurance and government waivers and alternative livelihoods.



	Emereoke	Obianga	Iwu	Inua Eyet
Social network	38	22	29	11
Physical assets	32	30	10	28
Credit facilities/insurance	22	32	26	20
Alternative livelihoods	37	29	15	19

Fig. 8. Local Coping strategies to mitigate flood impact on livelihoods

DISCUSSION OF RESULTS

(a) Demographic Characteristics

From Figure 2, more households were headed by men, and this may be attributed to nature of the livelihood common in the study areas. For instance, fishing is dominated by men. It was established from a key informant that most occupants of the areas were migrants from the adjourning local government area looking for cheap labour. Again, the majority of the people in the study areas were young as seen in Table 1. This may be due to the fact that, fishing activity is mostly carried out by young people since it is a tedious job that requires much energy. In line with this, one of the main informants commented: "*…the old people will not be fishing any longer rather they will go into subsistence farming and trading*". Furthermore, the outcome in Figure 3 revealed that the singles were the migrants and job seekers that came from the hinterland or adjourning local government areas according to the key informant. Again, Table 2 further revealed that household earning was negligible due to weather conditions especially when there was flooding which might hinder them from fishing, trading and farming. Nevertheless, taxes levied by the community councils and sea pirates might also rob them of their assets like boat, engine and goods on the high sea. Besides, the trends in Table 3 showed that the average household size was five members which further implies that many households had 3 - 5 members and this may be the reason the livelihood and earning got depleted so fast, and they must have been demanding much resources.

(b) Flooding Status by the Respondents and Nature of Flooding by Digital Elevation Model (DEM)

In Table 4, Iwuo Owo Opulom Community had more flooding destructive tendency than Obianga, though the floods were intense but not destructive. The respondents in Emereoke Community commented that the flood normally encroached overtime with intensity. Besides, the flooding status in Inua Eyet Ikot Community was not intense but might gradually become a threat if neglected by participants' assessment.

Furthermore, the south-east drainage pattern in Eastern Obolo (Obianga and Emeroke), as seen in Figure 4, was highly influenced by coastal flooding. Similarly, that of Ibeno (Inua Eyet Ikot and Iwuo Owo Opulom) was mostly influenced by the Kwa Iboe River and its tributaries. Again, rainfall as an important climatic variable had also induced flooding in the study areas. Rainfall intensity, duration and frequency are essential elements for assessing flood events and perturbation. As observed in Figures 5 and 6, the rainfall and temperature trends revealed that flooding had been increasing over the past ten years compared to the recent years because it had been very intense and destructive. It had destroyed a lot of facilities, hindered fishing, traders and water transportation systems predominately in Iwuo Owo Opulom. This finding agrees with Fabiyi and Yesuf [28] that the coastal communities are undergoing rapid changes through flood by ocean surges and increase rainfall. Key informant interviewed further revealed that some areas were under threat because their houses are almost taken over by flood.

(c) Livelihood Activities and their Vulnerabilities to Flooding

The finding of livelihood activities in the study areas in Figure 7 is in line with the comment of one of the key informants that fishing was the main livelihood activity. Both the respondents and the key informant indicated that fishing is lucrative but could be disrupted when the sea pirates hold sway and flooding as a result of rainfall which increased the tides. They also indicated that crop farming was promising but could be hindered by ocean surged which is salty and flooding during the rainy season. The fishing has contributed a lot of income to Obianga, Emeroke, Iwuo Okpom Opulom and Inua Eyet Ikot Communities. According to the informant, fishing indirectly affects every other economic activity like trading, crop production, teaching, manufacturing, amongst others. If the fishermen are not able to have a good harvest, it would indirectly affect other economic activities. Another key informant, a medicine seller, intimated that without the fishermen having a good harvest, he wouldn't sell and this would not go well with his family. It was discovered that some households also relied on livestock production for income generation. Again, trading was mostly undertaken by women in these communities. Fish processing (drying) was mostly done by the spouses of the fishermen, sold to other traders and to final consumers. This correlates with Jayanti *et al.* [29] that majority of coastal communities in the rural areas take up fishing and agriculture as their livelihood. Also, the results in Table 5 indicated that crop farming in Ibeno district was sensitive to flooding. The farmers had no access to weather services and flood warning system. Nevertheless, there was no much difference between male and female household heads with regards to vulnerability to flooding.

However, women argued that they might be swept away by flood water while attempting to excrete at the sea or river bank. Moreover, it is against the culture for female over there to expose themselves compared to male household head. Considering the three major livelihoods (crop production, farming and trading) and their vulnerability to flooding at the community level, the high vulnerability scores observed in Inua Eyet Ikot and Iwu Owo Opulom Communities, Ibeno district, were as a result of lack of access to credit facilities, waivers from government and international donor agencies. Household heads (fishermen) also argued that they were vulnerable because they lack alternative livelihood and money to alleviate their plight.

This agrees with Mmon and Aifesehi [30] that vulnerability is a cultural factor and may be difficult for the residence to relocate to low risk area.

Key informant interview intimated that he lost one of his children to storm surge which swept away the community in a certain night.

(d) Local Coping Strategies to Mitigate Impact of Flooding on Livelihoods

Looking at Figure 8, households deployed several coping strategies to build their livelihood resilience against flood stress and shocks. These include: (i) physical assets which were tools and equipment such as canoe, boats, fishing nets, farm tools, fertilizer, etc. used in their daily livelihood activities; (ii) social networks such as associations, village savings and loans, associations, unions, cooperatives etc.; (iii) credit facilities, insurance and government waivers and (iv) alternative livelihoods which involved the capacity to combine other livelihoods to reduce shocks from flood events and other natural disasters when they occur. As soon as the flooding sets in, their livelihoods could be hampered, thereby reducing their daily income. There were cases where crops, such as cassava, maize and vegetables, mostly cultivated by women or aged people in the communities at subsistence level, were ravaged by flooding; for instance, in Inua Eyet Ikot Community, in as much as there was no early warning system, households often times resolved to lay sand bags and sand stones to reduce surface run-off and flood water into the farms. Most of household heads in Obianga were traders and had better social network strength which they could fall back or be assisted financially in case of any disaster.

CONCLUSION AND RECOMMENDATIONS

Impact of flooding on livelihoods in Obianga, Emereoke, Inua Eyet Ikot and Iwuo Okpom Opulom Communities of Eastern Obolo and Ibeno Local Government Areas, Akwa Ibom State was examined. A total of 287 respondents were recorded. The demographic characteristics showed that more household heads were men, majority of the inhabitants were young people, whereas the singles were the immigrants. Household earning was very small with an average of five members. Iwuo Owo Opulom Community had more flooding destructive tendency than Obianga. Emereoke Community may become intense overtime whereas Inua Eyet Ikot Community was not intense but might gradually become a threat if neglected by participants' assessment. Three (3) major livelihoods were crop production, fishing and trading. Fishing, crop production and trading livelihoods in Ibeno district (Inua Eyet Ikot Community) had the highest vulnerability scores of 0.225, 0.178 and 0.165 respectively using. These imply that Inua Eyet Ikot Community is the most vulnerable to flooding than others. Local coping strategies to mitigate flood impact on livelihoods comprised of physical assets, social networks, credit facilities, insurance and government waivers and alternative livelihoods. It was suggested that drainage systems should be constructed and accurate flood warning system should be amounted especially in the flood prone areas through various agencies and NGOs.

CONFLICT OF INTEREST

None is declared.

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UTICAJ POPLAVA NA SREDSTVA ZA ŽIVOT I STRATEGIJE ZA UBLAŽAVANJE POSLEDICA U ODABRANIM PRIOBALNIM ZAJEDNICAMA U DRŽAVI AKVA IBOM, NIGERIJA

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Apstrakt: U ovoj studiji procenjen je uticaj poplava na egzistenciju u zajednicama Obianga, Emereoke, Inua Eyet Ikot i Iwuo Okpom Opulom u lokalnim samoupravnim područjima Istočnog Obolo i Ibena, u državi Akwa Ibom, Nigerija. Studija je usvojila unakrsno istraživanje sa uzorkom populacije sastavljenim od stanovnika priobalnih zajednica, koji je određen tehnikom namernog i slučajnog uzorkovanja pomoću formule autora Goddena.

Podaci su prikupljeni iz primarnih (upitnik koji su sastavili istraživači) i sekundarnih izvora (arhive, poljoprivredne/meteorološke stanice i Geološki zavod Sjedinjenih Država).

Prikupljeni podaci obuhvatali su demografske karakteristike učesnika, njihovu perspektivu o stepenu sklonosti ka poplavama u njihovim zajednicama, rezultat digitalnog modela elevacije (DEM) o sklonostima prema poplavama koristeći klimatske promenljive podataka između 2010. i 2019. godine, glavne aktivnosti za život, njihovu osetljivost na poplave i strategije suočavanja sa uticajem poplava na egzistenciju stanovništva.
Etička pitanja su razmotrena pre nego što su kopije upitnika primenjene i prikupljene nazad. Podaci su analizirani korišćenjem geografskih informacionih (GIS) tehnika, softvera ArcGis 10.3 i Microsoft Excel 2016. Intervjuisano je ukupno 287 ispitanika. Demografske karakteristike su pokazale da je više muškaraca bilo među starešinama domaćinstava, većina su bili mladi ljudi, dok su samci bili migranti.
Prihodi domaćinstava su bili zanemarljivi, sa prosečnom veličinom od pet (5) osoba. Zajednica na području Iwuo Owo Opulom imala je veću opasnost od mogućih poplava nego Obianga. Zajednica Emereoke može biti izložena poplavama tokom vremena, dok zajednica Inua Eyet Ikot može postepeno postati mesto ugroženo poplavama ako se zanemare kao procenjeni učesnici.
Tri (3) glavna načina života bila su: proizvodnja useva, ribolov i trgovina. Ribolov, proizvodnja useva i trgovina u okrugu Ibeno (zajednica Inua Eyet Ikot) imali su najviše ocene osetljivosti od 0,225, 0,178 i 0,165 respektivno. To implicira da je zajednica Inua Eyet Ikot najosetljivija na poplave, od ostalih proučavanih zajednica. Lokalne strategije suočavanja sa poplavama za ublažavanje uticaja poplava sastojale su se od zaštite fizičke imovine, društvenih mreža, kreditnih olakšica, osiguranja i vladinih odricanja od odgovornosti i alternativnih načina života. Predloženo je da se izgrade sistemi za odvodnjavanje i da se uspostavi precizan sistem upozoravanja na moguće poplave, posebno u područjima sklonim pojavama poplava, putem raznih agencija i nevladinih organizacija.

Ključne reči: *Poplave, sredstva za život, priobalne zajednice, strategije ublažavanja*

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MULTISPECTRAL ASSESSMENT OF UAV AND FIELD SPRAYER CHEMICAL CROP PROTECTION IN WHEAT

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Abstract: Modern agriculture increasingly relies on advanced technologies such as remote sensing and unmanned aerial vehicle (UAV) systems to monitor crop conditions and optimize pesticide application. This study aimed to compare the effects of pesticide application using UAV system DJI Agras T30 with those of a conventional field sprayer Kubota XTS326 and Kubota M135GX tractor in wheat production.

The research was conducted in Grmovci-Zemun (44°50′47″N, 20°11′07″E), Republic of Serbia, where the impact of pesticides on plant health was assessed using three vegetation indices: NDVI, SAVI, and EVI. Data were collected at three time points: before application, and 15 and 30 days after pesticide application (DAPA), using the DJI Phantom 4 Multispectral UAV.

The results showed that before pesticide application, all treatments exhibited high NDVI values (0.90–0.92). At 15 DAPA, the differences among treatments were minimal, whereas at 30 DAPA, the UAV system recorded the highest values for all indices (NDVI = 0.709; SAVI = 0.228; EVI = 0.209), compared with the field sprayer (NDVI = 0.686; SAVI = 0.217; EVI = 0.205) and the control (NDVI = 0.625; SAVI = 0.209; EVI = 0.188). These findings confirm that the UAV system ensured longer preservation of green biomass and a more favorable vegetative response compared with both the field sprayer and the control. The results indicate that UAV systems represent a valuable alternative in precision agriculture, providing more efficient pesticide application while reducing resource consumption.

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Keywords: *Unmanned aerial vehicles, pesticides, vegetation indices, remote sensing, precision agriculture, NDVI.*

INTRODUCTION

Wheat is cultivated under a wide range of climatic conditions and is one of the most important field crops worldwide. To achieve stable yields and high-quality grain, it is essential to maintain favorable agroecological conditions and provide effective protection against diseases and pests throughout the growing season. Chemical crop protection plays a crucial role, but its effectiveness depends on the application technology, dosage, droplet distribution, and prevailing weather conditions [1].

Remote sensing has emerged as a modern tool for monitoring crop conditions, enabling the timely detection of biotic and abiotic stresses before they become visually apparent. This approach is based on recording reflected electromagnetic radiation with sensors, while multispectral cameras make it possible to collect data across different parts of the spectrum [2,3,4]. Vegetation indices such as NDVI, EVI, and SAVI are widely used to quantify vegetation status, assess biomass, and detect plant stress, as they capture differences in the reflectance of visible and near-infrared radiation [5,6].

Unmanned aerial vehicle (UAV) systems have been increasingly applied in precision agriculture in recent years. Compared with satellites, UAV systems offer higher temporal and spatial resolution, allowing more frequent imaging and more detailed crop condition analysis. They can be equipped with multispectral, thermal, or RGB cameras and are also employed for chemical crop protection. Their advantages in pesticide application include reduced water and labor requirements, as well as the potential for improved pesticide coverage due to the downward airflow generated by propellers [1,2].

This study aimed to compare the effectiveness of pesticide application with a UAV system and a conventional field sprayer in wheat production by monitoring vegetation indices (NDVI, EVI, and SAVI). Special emphasis was placed on the dynamics of index values before and after treatment, as well as on vegetation uniformity within each treatment.

MATERIALS AND METHODS

The study was conducted on experimental plots in Grmovci (44°50′47″N, 20°11′07″E), Zemun municipality, on winter wheat cultivated in accordance with standard agronomic practices. The experiment included three treatments:

- T1 – Control (no pesticide application)
- T2 – Pesticide application using a UAV system
- T3 – Pesticide application using a conventional field sprayer

Each treatment plot covered an area of 0.12 ha, with 10 m isolation zones established between adjacent plots to minimize the risk of pesticide drift and cross-contamination. The boundaries of the experimental units were precisely marked immediately after sowing, ensuring clear spatial separation of treatments and preserving the integrity of the experiment.

Before sowing, the soil was plowed to a depth of 20 cm, and a starter fertilizer NPK (6:24:12) was applied at a rate of 300 kg/ha. The wheat variety used in this study was 'Sofru-RWA' (*Triticum aestivum L.),* a medium-early cultivar originating from Austria, characterized by an average plant height of 82 cm, good winter hardiness, resistance to lodging, and tolerance to common foliar diseases such as septoria and rust.
Sowing was carried out on October 21 at a seeding rate of 240 kg/ha, and crop emergence was observed approximately four weeks later. Successful overwintering enabled the continuation of vegetative growth in spring.

During the growing season, the crop was fertilized three times: at the beginning of stem elongation with 250 kg/ha of urea (46% N), before flowering with 100 kg/ha of calcium ammonium nitrate (CAN, 27% N), and again at the onset of flowering with an additional 100 kg/ha of CAN. Harvest took place at the beginning of July.

Two application systems were used for wheat protection. The first was a Kubota XTS326 field sprayer mounted on a Kubota M135GX tractor. This system operated with a spray volume of 200 l/ha, travels speed of 5 m/s, and a nozzle height of 0.5 m above the crop canopy. The main advantages of this system are its high field capacity and suitability for treating large areas. The second system was the DJI Agras T30 UAV, which applied a considerably lower spray volume of 30 l/ha, at a flight speed of 3 m/s and an altitude of 1.5 m above the canopy. The UAV system provides operational flexibility, precise application, and improved droplet deposition due to the additional airflow generated by the propellers. For both systems, the pesticide application was identical and expressed per unit area:

- Fungicide Delaro (1 L/ha)
- Insecticide Decis (0.075 l/ha)
- Adjuvant Inex (0.2 l/ha)

In addition to pesticide application, remote sensing was employed in the study. The entire experimental area was surveyed using a DJI Phantom 4 Multispectral UAV flown at an altitude of 20 m. This UAV system is equipped with a camera containing six CMOS sensors: one RGB and five multispectral bands (blue, green, red, red edge, and near-infrared). It also features a high-precision RTK GNSS module, offering positioning accuracy of 1 cm horizontally and 1.5 cm vertically, making it highly suitable for precise mapping and vegetation analysis.

Imaging was conducted at three time points: before treatment (April 27, 2023), 15 days after application (May 12, 2023), and 30 days after application (May 27, 2023). The acquired images were processed using Solvi software, where three vegetation indices, NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), and SAVI (Soil-Adjusted Vegetation Index), were calculated for each treatment plot. The indices were computed according to the following formulas:

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad .....[1]$$

where is

NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum

$$SAVI = \frac{1.5*(NIR-Red)}{(NIR-Red+0.5)} \qquad \text{...........[2]}$$

where is

NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum
1.5 – coefficient that enhances the distinction between vegetation and soil
0.5 – soil adjustment factor added to reduce the influence of bare soil on the index

$$\text{EVI} = 2.5 * \frac{(NIR-Red)}{(NIR+6*Red-7.5*Blue+1)} \qquad \text{......[3],}$$

where is
NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum
Blue – reflectance in the blue region of the spectrum
2.5 – coefficient that increases the sensitivity of the index to vegetation differences
7.5 – coefficient that adjusts the influence of blue reflectance
6 – coefficient that adjusts the influence of red reflectance
1 – coefficient added to prevent division by zero in the denominator

The analysis included mean, minimum, and maximum values, and changes relative to the pretreatment state were also expressed in relative terms (15 DAPA and 30 DAPA).

RESULTS AND DISCUSSION

The analysis of NDVI values indicated that before pesticide application, all three treatments displayed high average values, signifying well-developed vegetation (see Table 1). The control group (T1) recorded the lowest NDVI at 0.900, while the protected treatments showed slightly higher values. Notably, the UAV system (T2) achieved the highest average NDVI at 0.921.

At 15 DAPA, the average NDVI values increased slightly across all treatments. Differences among the UAV system (T2, 0.915), the field sprayer (T3, 0.912), and the control (T1, 0.917) were negligible, suggesting that treated crops maintained a vegetative status comparable to the control. However, during this period, the chemically treated plots demonstrated greater stability, whereas the control exhibited a narrower range of minimum and maximum values, which may indicate increased crop heterogeneity. At 30 DAPA, a notable decrease in NDVI values was observed across all treatments, corresponding to the expected reduction in photosynthetically active surface area during the later stages of wheat development. The sharpest decline occurred in the control (T1, 0.625), while the treated plots retained higher NDVI values. The UAV treatment (T2, 0.709) had the highest value, followed closely by the field sprayer (T3, 0.686). Moreover, the UAV treatment showed the narrowest range of NDVI values (0.707–0.711), indicating greater spatial homogeneity and crop uniformity. In contrast, both the control and the sprayer treatments displayed wider NDVI ranges (e.g., T1: 0.571–0.699), reflecting more pronounced variability in vegetation condition.

Table 1. Mean, min., and max. NDVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	NDVI_mean	NDVI_min	NDVI_max	NDVI_mean	NDVI_min	NDVI_max	NDVI_mean	NDVI_min	NDVI_max
T1	0.9	0.859	0.947	0.917	0.878	0.959	0.625	0.571	0.699
T2	0.921	0.913	0.943	0.915	0.88	0.952	0.709	0.707	0.711
T3	0.903	0.835	0.972	0.912	0.893	0.935	0.686	0.656	0.736

Before pesticide application, all experimental plots exhibited high SAVI values (Table 2), indicating good vegetation condition. The field sprayer treatment recorded the highest average value (T3 = 0.420), followed by the UAV treatment (T2 = 0.398) and the control (T1 = 0.368). Differences among treatments at this stage were not pronounced and primarily reflected natural crop variability.

At 15 DAPA, SAVI values decreased across all treatments. The UAV treatment recorded the highest average value (T2 = 0.319), while the sprayer (T3 = 0.309) and the control (T1 = 0.288) were lower. These results suggest that the UAV system enabled slightly better preservation of vegetation compared with the other treatments. At 30 DAPA, the average SAVI values further declined. The lowest value was observed in the control (T1 = 0.209), while the protected treatments retained higher values: UAV (T2 = 0.228) and sprayer (T3 = 0.217). In addition to higher mean values, the UAV system showed the smallest reduction relative to the initial state, indicating more stable preservation of leaf biomass.

Overall, the SAVI results confirmed the NDVI findings, with the UAV treatment providing the most favorable vegetative response and the smallest decline in vegetation index over 30 days after application, whereas the control showed the steepest decrease. These findings are consistent with those of Chen et al. (2015) [7], who demonstrated that vegetation indices reliably reflect crop dynamics and can be used to estimate crop development and evapotranspiration coefficients (Kcb), particularly under biotic stress conditions such as stripe rust infection.

Table 2. Mean, min., and max. SAVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	SAVI_mean	SAVI_min	SAVI_max	SAVI_mean	SAVI_min	SAVI_max	SAVI_mean	SAVI_min	SAVI_max
T1	0.368	0.299	0.498	0.288	0.113	0.474	0.209	0.075	0.354
T2	0.398	0.314	0.503	0.319	0.154	0.488	0.228	0.121	0.354
T3	0.42	0.328	0.518	0.309	0.156	0.477	0.217	0.116	0.337

Before pesticide application, all three treatments exhibited high EVI values (Table 3), indicating well-developed vegetation. The highest average value was recorded in the field sprayer treatment (T3 = 0.402), while the UAV system (T2 = 0.398) and the control (T1 = 0.384) showed slightly lower values. Differences among treatments at this stage were not significant.

At 15 DAPA, average EVI values decreased across all treatments. The lowest value was observed in the field sprayer treatment (T3 = 0.255), while the control showed intermediate values (T1 = 0.287). The highest EVI was recorded in the UAV treatment (T2 = 0.319), indicating a more favorable vegetative response compared with both the sprayer and the control. These results are consistent with the findings of Zou et al. (2017) [8], who reported that EVI is highly sensitive to changes in vegetation structure and effectively reflects variations in leaf area and photosynthetically active biomass.

At 30 DAPA, EVI values further declined across all treatments, consistent with the physiological reduction of greenness during the later phenophases of wheat development. The UAV system (T2 = 0.209) and the field sprayer (T3 = 0.205) had nearly identical values, while the control recorded slightly lower values (T1 = 0.188). Although the differences between the treated variants were minor, both maintained higher average values than the control, indicating a positive effect of pesticide application on the preservation of leaf biomass.

Table 3. Mean, min., and max., EVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	EVI_ mean	EVI_ min	EVI_ max	EVI_ mean	EVI_ min	EVI_ max	EVI_ mean	EVI_ min	EVI_ max
T1	0.384	0.29	0.517	0.287	0.102	0.492	0.188	0.064	0.324
T2	0.398	0.307	0.531	0.319	0.14	0.514	0.209	0.106	0.323
T3	0.402	0.324	0.528	0.255	0.141	0.45	0.205	0.1	0.31

The obtained vegetation index results demonstrated that the UAV system ensured a higher and more stable vegetative response compared with the field sprayer and the control, particularly 30 days after pesticide application (30 DAPA). These findings are consistent with those of Author [9], who reported that decreases in NDVI values directly correlate with the progression of disease symptoms, as well as Authors [10], who confirmed the reliability of vegetation indices in assessing crop vitality. The more stable NDVI, SAVI, and EVI values observed in the UAV treatment suggest a more uniform pesticide distribution and prolonged preservation of leaf biomass.

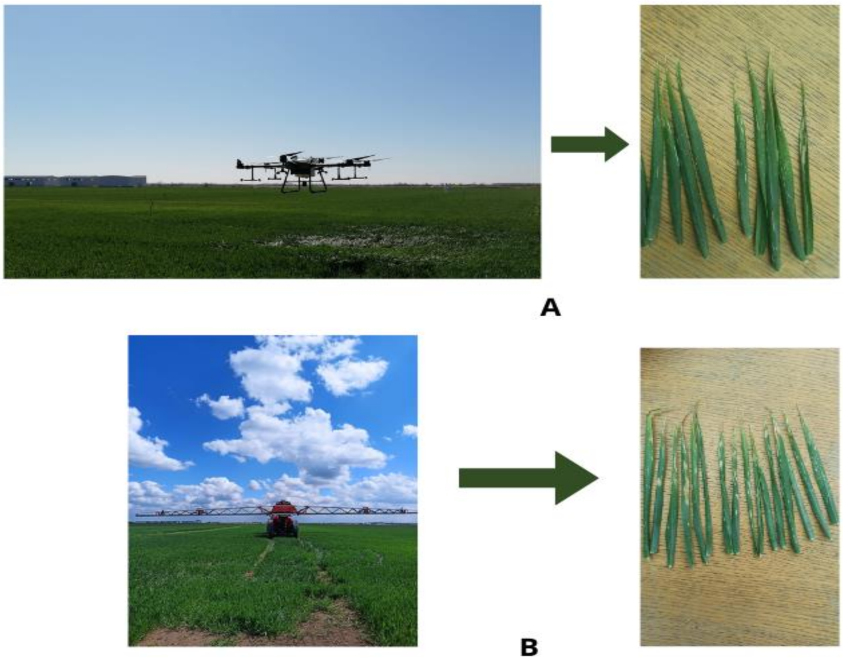

Figure 1. Application systems for heat protection: A – UAV system with crop damage from cereal leaf beetle; B – field sprayer with crop damage from cereal leaf beetle.

In addition to the physiological decline of vegetation indices due to the transition of wheat to later phenophases, the results were also influenced by biotic stress, primarily damage from the cereal leaf beetle (*Oulema melanopus*) and infections caused by leaf rusts (*Puccinia striiformis, P. graminis*). The most pronounced decline in vegetation indices was observed in the control and field sprayer treatments (Figure 1), which can be attributed to poorer coverage and more heterogeneous pesticide deposition [11,12]. In contrast, the UAV treatment exhibited lower variability and a more homogeneous crop structure, as reflected by the narrower range of minimum and maximum values compared with the other treatments.

The results of this study indicate that UAV systems can provide significant advantages in precision agriculture by enabling reduced spray volumes, improved efficiency of pesticide application, and better preservation of vegetation under pest and disease pressure. These findings highlight the potential of UAV technology as a sustainable alternative to conventional field sprayers, while also emphasizing the need for further research across multiple locations and diverse production conditions.

CONCLUSION

The results of this study showed that all vegetation indices (NDVI, SAVI, and EVI) consistently demonstrated the advantages of UAV application compared with the conventional field sprayer and the control.

No significant differences were observed among treatments before pesticide application; however, after application, particularly at 30 DAPA, the UAV treatment recorded higher and more stable index values, along with lower variability within the treated area. The control exhibited the steepest decline across all indices, confirming the importance of pesticide application for maintaining vegetative activity and wheat yield.

The differences observed between the UAV system and the conventional sprayer can be attributed to better leaf coverage and more uniform pesticide deposition achieved with the UAV system, which likely mitigated the negative effects of biotic stress (cereal leaf beetle damage and leaf rust infections). Overall, the findings confirm that UAV systems, in addition to reducing spray volumes, can provide effective and uniform protection of wheat, offering potential for more sustainable crop production.

Future research should involve multiple growing seasons and diverse locations, along with a more detailed quantification of biotic and abiotic stress impacts, to further validate and expand the applicability of these results.

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MULTISPEKTRALNA PROCENA HEMIJSKE ZAŠTITE PŠENICE PRIMENOM UAV SISTEMA I RATARSKE PRSKALICE

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Abstract: Savremena poljoprivreda sve više se oslanja na napredne tehnologije kao što su daljinska detekcija i sistemi bespilotnih letelica (UAV) za praćenje stanja useva i optimizaciju primene pesticida.

Cilj studije bio je da se uporede efekti primene pesticida pomoću UAV sistema DJI Agras T30 sa efektima primene kod konvencionalne zaštite sa agregatom traktor Kubota M135GX i prskalice Kubota XTS326 u proizvodnji pšenice.

Istraživanje je sprovedeno u mestu Grmovci (44°50′47″N, 20°11′07″E), Opština Zemun, Republika Srbija, gde je uticaj pesticida na zdravlje biljaka procenjen pomoću tri vegetaciona indeksa: NDVI, SAVI i EVI.

Podaci su prikupljani u tri vremenske tačke: pre primene pesticida, 15 i 30 dana nakon primene (DAPA), korišćenjem bespilotne letelice DJI Phantom 4 Multispectral.

Rezultati su pokazali da su pre primene pesticida svi tretmani imali visoke vrednosti NDVI indeksa (0,90–0,92). Petnaestog dana nakon primene (15 DAPA) razlike između tretmana bile su minimalne, dok je 30. dana (30 DAPA) UAV sistem zabeležio najviše vrednosti za sve indekse (NDVI = 0,709; SAVI = 0,228; EVI = 0,209), u poređenju sa traktorskim prskalicama (NDVI = 0,686; SAVI = 0,217; EVI = 0,205) i kontrolom (NDVI = 0,625; SAVI = 0,209; EVI = 0,188). Ovi nalazi potvrđuju da je UAV sistem DJI Agras T30 omogućio duže očuvanje zelene biomase i povoljniji vegetativni odgovor u poređenju sa konvencionalnom zaštitom prskanjem i kontrolnim tretmanom.

Rezultati ukazuju na to da UAV sistemi predstavljaju vrednu alternativu u preciznoj poljoprivredi, omogućavajući efikasniju primenu pesticida uz smanjenu potrošnju resursa.

Ključne reči: *Bespilotne letelice, pesticidi, vegetacioni indeksi, daljinska detekcija, precizna poljoprivreda, NDVI.*

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RESILIENCE STRATEGIES TO COMBAT THE SHOCKS OF ECONOMIC SITUATION AMONG CASSAVA PROCESSORS IN OGBOMOSO AGRICULTURAL ZONE OF OYO STATE, NIGERIA

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Abstract. Cassava (*Manihot esculenta Crantz*) is the second most consumed staple food crop after maize in Africa and is the main food security crop after maize in Nigeria. A study, aimed at analyzing resilience strategies adopted by cassava processors to combat economic situation in Ogbomoso Agricultural Zone of Oyo State, was conducted. Surveys were conducted in three blocks (Oriire, Ogo-Oluwa and Surulere). A structured questionnaire was administered to a total of 130 randomly selected households. Majority of the respondents had a mean age ranging between 46 and 51 years. It was also revealed that majority (85.0%, 92.5% and 95.7% respectively) were married. The levels of usage of improved cassava processing methods range between 57.5% and 65.2%. Cassava processors engaged majorly in value addition to products with a weighted mean score (WMS) of 3.04 to combat economic situation in the study area.
The result of linear regression analysis indicated that the usage of improved cassava processing methods (t =3.436***; p = 0.01; Adjusted R^2 value = 87.13%) was significantly related with the resilience strategies adopted to combat the shocks of economic situation. It was concluded that different resilience strategies were adopted which had significant influence in addressing the economic situation in the study area.

There is therefore need for all stakeholders in rural development to gear up efforts to educate the respondents on reliable resilience strategies in cushioning the effects of economic situation.

Keywords: *Cassava, processors, value addition, resilience, shocks, economic situation, processing equipment, household level.*

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INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is the second most consumed staple food crop after maize in Africa. Cassava production is vital to the economy of Nigeria as the country is the world's largest producer of the commodity, with about 54 million metric tonnes [1,2]. Cassava production stood at about 278 million tonnes; Africa's total production was about 170 million tonnes (about 56% of world production) [3]. Nigeria produced about 60 million tonnes [3]. The majority (88%) of cassava produced in Africa is used for human food, with over 50% used in the form of processed products [4]. Other uses in animal feed and for industrial purposes (starch, ethanol) are as yet very minor. Although the crop is considered as a staple in many countries, this situation is changing in some countries where cassava is now an industrial and cash crop [5].

Rural communities can be understood as vulnerable social ecological systems (SES) [6]. So, there is need to build resilience to withstand internal and external stresses from social, economic, political and health status changes [7,8]. It had been established that many aspects of adaptive capacity reside in social networks [9] and that these are a crucial source of resilience [10-12]. Resilience has emerged as a key concept across disciplines for investigating responses to changes in human and ecological systems [13]. Apparently, people's capabilities are said to play a key role in the response to the current economic crisis in Nigeria. In respect of the aforementioned evidences, investigations into the role of resilience capacities especially through social networks during social, economic and ecological changes is growing at a fast pace [14].

It is therefore highly imperative to analyze resilience strategies adopted by cassava processors to combat current economic situation in Oyo State.

Objectives of the study

The general objective of the study is to analyze resilience strategies adopted by cassava processors to combat current economic situation in Ogbomoso Agricultural Zone of Oyo State.

Specific objectives of the study

The specific objectives of the study are to;

(1) describe the socio-economic characteristics of the rural cassava processors in Ogbomoso Agricultural Zone of Oyo State, Nigeria; (2) determine the level of usage of improved cassava processing methods; and (3) ascertain the resilience strategies employed to combat the shocks of economic situation among cassava processors in the study area.

RESEARCH METHODOLOGY

Study Area

The study was carried out in Ogbomoso Agricultural Zone of Oyo State, Nigeria. Oyo State lies between latitude 70^0N and 190N of the equator and between 2.5^0E and 5^0E of the prime meridian. The State has a total population of 5.6 million going by the provisional population figure of 2006 [15], and a land area of 27,140,000 square kilometer. Annual mean rainfall ranges above 1000mm; rainy season in the state averages eight months in a year.

Mean temperature varies from daily minimum of 18.9^{0}C to a daily maximum of 35^{0}C. Humidity is quite high in Oyo State. Relative humidity in the State is 70 percent with a maximum of about 60 percent in the evening and a maximum of around 80 percent in the morning. The settlement pattern shows that so many people of different Nigerian ethnic background reside in Oyo State. The Yoruba ethnic group constitutes the majority of the population living in Oyo State. There are also non-Nigerians who live in Oyo State.

Population of this study involved all cassava processors in Ogbomoso Agricultural Zone of Oyo State. The study employed multistage sampling technique in selecting sample for this study. The first stage involved purposive selection of 3 blocks from Ogbomoso agricultural zone which are known to be rural in nature. According to [16] and [17], a purposive sample is a non-representative subset of some larger population, and is constructed to serve a very specific need or purpose. Thereafter, there was random selection of three (3) cells from each of the selected blocks. Next, the list of registered cassava processors in each of the selected cells were secured from the ADP section of the respective local government areas of the selected cells. A proportionate sampling procedure was utilized in the selection of one hundred and thirty (130) respondents from Ogbomoso Agricultural Zone for the study.

An interview schedule was used to obtain the necessary data (socio-economic characteristics, level of usage of improved cassava processing methods; and the resilience strategies to combat the shocks of economic situation among cassava processors in the study area.

A very important part of the questionnaire construction process is its piloting, known as pre-testing. This involves testing research instrument in conditions as similar as possible to the research situation, in order to check for glitches in wording of questions, lack of clarity of instructions etc. The pretest was conducted using the same protocol and setting as the survey and is typically conducted once the questionnaire and procedures have been finalized. Therefore, in this study, the interviewed schedule was administered on 13 respondents who were cassava processors in the rural areas outside the study area in order to remove the ambiguous sentences, statements or questions that were likely misunderstood.

The data obtained were analyzed using descriptive and inferential statistics. The descriptive tools include frequency distribution and percentages, while for inferential statistics linear regression analysis was used for the formulated hypothesis of the study.

RESULTS AND DISCUSSIONS

Socio-economic Characteristics

Table 1 indicated that the mean age of the respondents range between 46 and 51 years respectively. This implies that most of the respondents are still active to engage in cassava processing. The mean age in this research work is similar to the mean age (52 years) reported by [18].

It was also revealed that majority (85.0%, 92.5% and 95.7%) of the respondents from Surulere, Oriire and Ogo-Oluwa were married respectively. This is similar with the work of other authors [19] who claimed that cassava processing enterprise is occupied by married people (especially the women).

This development indicated the likelihood of spouse and/or other family members getting involved in the cassava processing enterprise especially in the area of labour supply. Similarly, the sharing of the proceeds (products and/or income) may also be determined through decision making in a family setting arrangement.

Table 1. Distribution of respondents by Socio-economic Characteristics (n = 130)

Socio-economic Characteristics	Oriire (n = 67)		Ogo-Oluwa (n = 23)		Surulere (n = 40)	
	Freq.	%	Freq.	%	Freq.	%
Age						
≤ 30	0	0.0	1	4.3	1	2.5
31 – 40	8	12.0	2	8.7	10	25.0
41 – 50	26	38.8	10	43.5	16	40.0
51-60	25	37.2	8	34.8	3	7.5
Above 60	8	12.0	2	8.7	10	25.0
Mean	51		49		46	
Marital status						
Single	2	3.0	1	4.3	4	10.0
Married	62	92.5	22	95.7	34	85.0
Separated	0	0.0	0	0.0	0	0.0
Widowed	3	4.5	0	0.0	2	5.0

Source: Field Survey, 2025.

Categorization of level of usage of improved cassava processing methods

Table 2 showed the categorization of the level of usage of improved cassava processing methods. It was revealed that levels of usage of improved cassava processing methods across the three blocks were at moderate levels, ranging between 57.5% and 65.2%. This development connotes overreliance on traditional methods of processing since cassava is usually consumed in processed forms. Obviously, cassava processing by traditional methods is labour-intensive and time consuming. This finding is consistent with the report of some scholars [20] who opined that industrial utilization of cassava products is increasing but still accounts for less than 5% of the total production. Similarly, the trend in the level of usage of improved cassava processing methods observed in this current research is a clear indication of increasing gap in technological development and transfer across communities. It is important to recognize that the usage of a given processing methods dynamics are also highly context-specific, with unique structures and organization in different locations and regions.

Increasing sensitization and awareness of proven technologies especially on value addition to products is essential to enhance optimal utilization of value addition technologies thereby engendering sustainable income flow for the end users.

However, it must be noted that level of usage of improved cassava processing methods can become strained when any one of the factors required for their proper operation is affected negatively.

Table 2: Distribution of respondents by categorization of level of usage of improved cassava processing methods

Categorization	Oriire (n = 67)		Ogo-Oluwa (n = 23)		Surulere (n = 40)	
	Freq.	%	Freq.	%	Freq.	%
Low	12	34.3	3	13.0	9	22.5
Medium	42	62.7	15	65.2	23	57.5
High	13	19.4	5	21.8	8	20.0
Mean	27.82		27.52		27.74	
Standard dev.	5.947		4.601		5.610	

Source: Field Survey, 2025

Resilience strategies adopted by cassava processors to combat the shocks of economic situation

Table 3 showed that cassava processors employed the following strategies to adapt with economic situation in Ogbomoso Agricultural zone; value addition to products with a weighted mean score (WMS) of 3.04, livelihood/income diversification (WMS = 2.95), seeking assistance from government (WMS = 2.52), participation in village co-operative society (WMS = 2.35), the use of remittance (WMS = 2.34), early warning system (WMS = 2.14) and skills training/acquisition opportunities (WMS = 2.10). From the finding, it was observed that cassava processors employed diverse portfolio to combat economic situation. Moreover, value addition happened to be main coping strategy adopted by the cassava processors to combat the shocks of economic situation which could be as a result of numerous benefits inherent in it. In short, value addition could help sustain food supply chain through the development of more stable value added cassava products. It must be noted that food supply chains risk disruption from many different types of shocks, including conflict, climate vulnerability, human and animal diseases, financial shocks and local disasters [21,22]. These types of shocks have the potential to negatively impact multiple dimensions of food security. For example, recently experienced shocks, including COVID-19 and the war in Ukraine, have resulted in uneven food availability due to blocked trade, lack of inputs or labour shortages. Supply chain disruptions can also lead to higher food prices that diminish food access and can lead to consumers shifting to less healthy diets. Markets can also become unstable, and prices can rise sharply due to sudden trade restrictions, low stock levels, transportation blockages and infrastructural damage or weakness. Disruptive food system shocks can also lead to wastage, which undermines sustainability. And food supply chain vulnerabilities can deepen inequalities and weaken livelihoods in ways that diminish the ability of food system actors (including producers, workers, traders and consumers) to interact with food systems on their own terms, [23].

Table 3. Distribution of respondents by Resilience strategies adopted by cassava processors to combat current economic situation

Resilience strategies	WMS	Rank
Seeking assistance from government	2.52	3rd
Livelihood/ income diversification	2.95	2nd
Value addition to products	3.04	1st
Skills training/acquisition opportunities	2.10	7th
The use of remittance	2.34	5th
Participation in village co-operative society	2.35	4th
Early warning system	2.14	6th

Source: Field Survey, 2025

Relationship between usage of improved cassava processing methods and resilience strategies adopted to combat the shocks of economic situation

Table 4 showed the result of linear regression analysis showing the relationship between usage of improved cassava processing methods and resilience strategies adopted to combat the shocks of economic situation. It was revealed that the usage of improved cassava processing methods (t =3.436***; p=0.01) was significantly related with the resilience strategies adopted to combat the shocks of economic situation. The adjusted R square value was found to be 87.13% implying that usage of improved cassava processing methods had a strong decisive influence on the resilience strategies adopted to combat the shocks of economic situation. The fact that the relationship was significant at 1% level further enacting the unparalleled contributions of technological development in reinforcing resilience strategies adopted to combat the shocks of economic situation. In fact, the adoption of resilience strategies to combat the shocks of economic situation will increase by 30.4% with the usage of improved cassava processing methods. This could be because cassava processors using improved processing methods will get more quality products with high premium which will enhance their income level thereby improving household food security. This finding is in tandem with the assumption of [18] who believed that access to improved technologies will expose the end users to agricultural information and technology, which will enhance productivity and improve household food security.

Table 4. Result of linear regression analysis of relationship between usage of improved cassava processing methods and resilience strategies adopted to combat the shocks of economic situation

Variable	B-Value	Std. Error	T-Value	P-Value
Constant	42.266	2.514	16.815	0.000
Resilience index	0.305	0.089	3.436***	0.001

Adjusted R square Value = 0.8713 (87.13%)
***Significant at 1% level
Source: Field Survey, 2025.

CONCLUSION AND RECOMMENDATIONS

It was concluded that different resilience strategies were adopted which had significant influence on the cassava processors in combating the economic situation in Ogbomoso Agricultural zone of Oyo State, Nigeria. There is therefore need for all stakeholders in rural development to gear up efforts to educate the respondents on reliable resilience strategies in cushioning the effects of current economic situation.

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STRATEGIJE OTPORNOSTI ZA ELIMINSANJE NEPOVOLJNIH EFEKATA EKONOMSKE SITUACIJE KOD PRERADE KASAVE U POLJOPRIVREDNOJ OBLASTI OGBOMOSO U DRŽAVI OYO, NIGERIJA

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Apstrakt: Kasava (*Manihot esculenta Crantz*) ili Manioka je druga najčešće konzumirana osnovna kultura posle kukuruza u Africi i glavna kultura za bezbednost hrane posle kukuruza u Nigeriji. Sprovedena je studija, čiji je cilj bio da analizira strategije otpornosti koje su usvojili prerađivači kasave kako bi se suočili sa ekonomskom situacijom u poljoprivrednoj zoni Ogbomoso u državi Oyo.

Ankete su sprovedene u tri bloka (oblasti Oriire, Ogo-Oluwa i Surulere). Strukturirani, prilagođen upitnik je primenjen na ukupno 130 slučajno odabranih domaćinstava. Većina ispitanika imala je prosečnu starost između 46 i 51 godine. Takođe je uvrđeno da je većina (85,0%, 92,5% i 95,7% respektivno) bila u braku. Nivoi korišćenja poboljšanih metoda prerade Kasave kreću se između 57,5% i 65,2%.

Prerađivači Kasave su se uglavnom bavili dodavanjem vrednosti proizvodima sa ponderisanom prosečnom ocenom (WMS - Weighted Mean Score) od 3,04 kako bi se suočili sa ekonomskom situacijom u području istraživanja.

Rezultat linearne regresione analize pokazao je da je upotreba poboljšanih metoda prerade Kasave (t = 3,436***; p = 0,01; Prilagođena vrednost R^2 = 87,13%) značajno povezana sa strategijama otpornosti usvojenim za borbu protiv šokova ekonomske situacije. Zaključeno je da su usvojene različite strategije otpornosti imale značajan uticaj na rešavanje ekonomske situacije u proučavanom području. Stoga je potrebno da svi akteri u ruralnom razvoju pojačaju napore kako bi edukovali ispitanike o pouzdanim strategijama otpornosti u ublažavanju nepovoljnih efekata ekonomske situacije.

Ključne reči: *Kasava, prerađivači, dodavanje vrednosti, otpornost, šokovi, ekonomska situacija, oprema za preradu, tip domaćinstva.*

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INTEGRISANI MODEL ZA PROCENU ODRŽIVOSTI BEZBEDNOSTI KRETANJA TRAKTORA U JAVNOM SAOBRAĆAJU REPUBLIKE SRBIJE

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Sažetak: Traktori predstavljaju značajnu kategoriju učesnika u saobraćaju. Pored toga, oni su ključni faktor u svakodnevnom radu i razvoju poljoprivrednih aktivnosti u celom svetu. Tokom obavljanja svojih radnih aktivnosti traktori su svakodnevno prisutni na javnim i atarskim putevima. U vezi sa tim, traktori su značajno prisutni u saobraćajnim nezgodama na putevima i nesrećnim događajima koji se dešavaju van javnih puteva. Posledica navedenih nezgoda i nesrećnih događaja veoma su velike. Do sada je urađen veliki broj studija i istraživanja koje su analizirale način stradanja traktora u saobraćaju. Identifikovani su neki od ključnih faktora koji su povezani sa nastankom i posledicama tih nezgoda. U radu su postavljene dve radne hipoteze za istraživanje i testiranje. Kao prilog tim istraživanjima kreiran je model koji je analizirao uticaj, većeg broja registrovanih traktora u odnosu na broj registrovanih poljoprivrednih gazdinstava, na nastanak nezgoda sa učešćem traktora i posledica po opštinama u Republici Srbiji. Ovim modelom izvršeno je ispitivanje doprinosa nezavisnih promenjivih (broj registrovanih traktora i broja poljoprivrednih gazdinstava po opštinama) u zavisnoj promeljivoj koja je obuhvatila ukupan broj saobraćajnih nezgoda sa učešćem traktora. Korišćenjem statističkih podataka i primenom standardne višestruke regresione analize u Programskom statističkom paketu SPSS25 utvrđena je zavisnost promenljivih u istraživanju.

Zaključeno je da broj registrovanih vozila ima različit uticaj od broja registrovanih gazdinstava i da zastupljenost broja vozila u ukupnom broju gazdinstava ima različit uticaj na posledice saobraćajnih nezgoda sa učešćem traktora.

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***Ključne reči**: Traktori, bezbednost saobraćaja, saobraćajne nezgode.*

UVOD

Učešće traktora u saobraćajnim nezgodama i njihove posledice predstavljaju problem koji je u velikom porastu poslednjih godina [3]. Veliki broj dosadašnjih studija [6], [7], [8] koje su istraživale bezbednost traktora u saobraćaju došle su do zaključka da nedostaju pouzdane baze podataka o učešću traktora u saobraćajnim nezgodama. Istraživanja su takođe identifikovala veliki broj neslaganja u terminologiji i načinima prikljupljanja i obrade podataka o predmetnim nezgodama [2]. Traktori su po Zakonu o bezbednosti saobraćaja na putevima od 2010. godine definisani kao motorno vozilo koje ima najmanje dve osovine i koje je prvenstveno namenjeno za vučenje, guranje, nošenje ili pogon izmenjivih priključaka za izvođenje prvenstveno poljoprivrednih, šumskih ili drugih radova i za vuču priključnih vozila za traktor. Kada se sagledaju međunarodna iskustva, može se zaključiti da se u Zakonima, podzakonskim aktima i drugim normativnim i statističkim dokumentima traktori različito definišu i kategorišu, što sa aspekta analize stanja bezbednosti saobraćaja predstavlja značajan problem kod poređenja indikatora bezbednosti saobraćaja na međunarodnom nivou [5].

Jedan od najvećih uzroka nastanka saobraćajnih nezgoda sa učešćem traktora predstavlja upravo njegovo prevrtanje [1].

Takođe, jedan od dominatnih uzroka stradanja traktora često je povezan sa stanjem njegove tehničke ispravnosti [13], [14], [25].

Postoje istraživanja [10], [11], [16], u kojima se došlo do zaključka, koji se odnosi na to da su traktori na putevima zastupljeni u veoma malom obimu u strukturi saobraćajnog toka, ali su njihove posledice u poređenju sa drugim učesnicima u saobraćaju značajno veće kada se uzme u obzir procentualna zastupljenost. Suštinski traktori i nisu projektovani da se kreću po javnim putevima, već prvenstveno po njivama [15], [26], [27].

Danas su lokacije njiva od sedišta poljoprivrednih gazdinstava prilično udaljene. Tome doprinosi izmeštanje sedišta poljoprivednih gazdinstava iz urbanih područja [4] i to da zbog veličina njihov pristup je jedino moguć korišćenjem javnih puteva [9]. Najviše nezgoda se događa van naseljenih mesta gde se traktori najčešće kreću po lokalnim putevima [24], [25], [27].

U ovom radu prikazano je istraživanje koje se odnosi na analizu broja registrovanih traktora i ukupnog broja poljoprivrednih gazdinstava po opštinama u Republici Srbiji i njihov doprinos nastaku saobraćajnih nezgoda sa učešćem traktora.

METODE ISTRAŽIVANJA

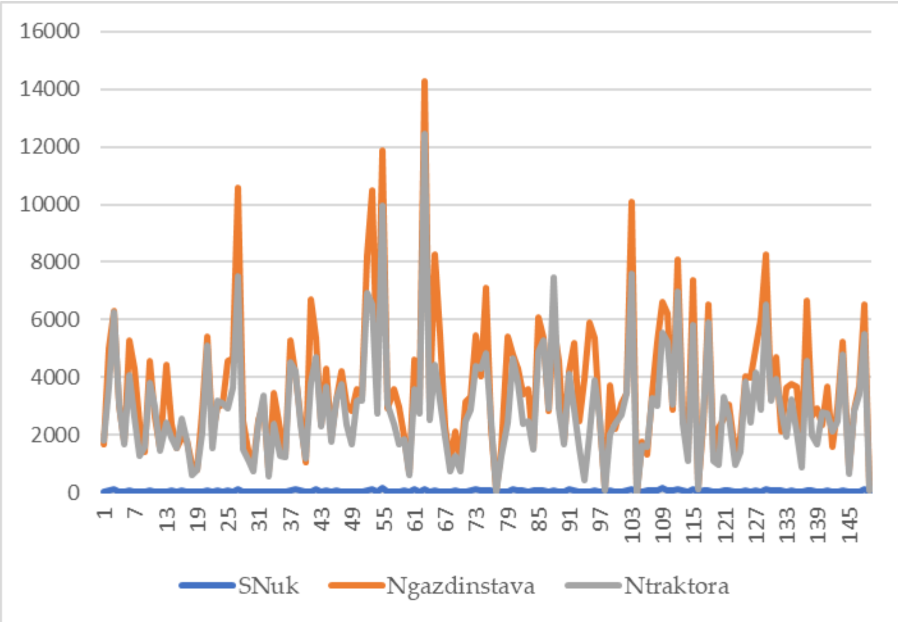
Rezultati istraživanja pokazuju da su nesreće sa mobilnom poljoprivrednom mehanizacijom u Republici Srbiji veoma česta pojava [24], [25].

Na području Republike Srbije u toku 2022. godine ukupno je registrovano 543.374 poljoprivrednih gazdinstava [20]. U istoj godini registrovano je ukupno 437.663 traktora. Dakle, zastupljenost traktora u 2022. godini je iznosila 0,8 traktora po gazdinstvu.

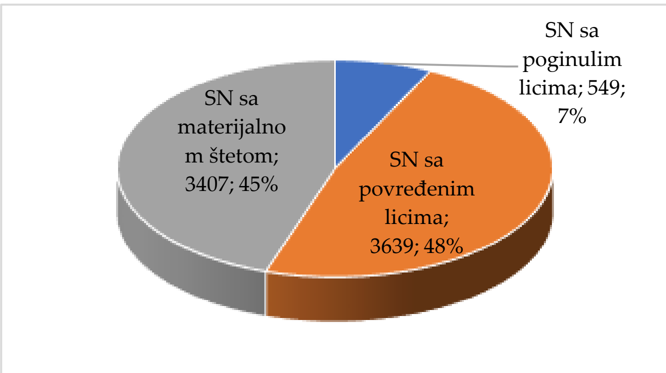
Uporedni prikaz ukupnog broja registrovanih traktora (N-traktora) ukupnog broja registrovanih gazdinstava (N-gazdinstava) i ukupnog broja saobraćajnih nezgoda za period 2010-2022. godine (SN-ukupno) prikazan je na slici 1.

U periodu od 2010. do 2022. godine na putevima u Republici Srbiji dogodilo se ukupno 7.595 saobraćajnih nezgoda sa učešćem traktora. Kao što je prikazano na slici 2 od ukupnog broja 7,3% (549) su nezgode sa poginulim licima, 47,9% (3.639) nezgoda sa povređenim licima i 44,8% (3.407) nezgoda sa materijalnom štetom [19].

Saobraćajne nezgode sa učešćem traktora čine 7,8% od ukupnog broja svih nezgoda sa poginulim licima u Republici Srbiji u posmatranom periodu 2010-2022 godine. Isto tako, nezgode sa povređenim licima gde su učestvovali traktori čine 4,4% od ukupnog broja svih nezgoda sa povređenim licima.



Grafik. 1. Uporedni statistički prikaz SN-ukupno, N-gazdinstava i N-traktora, [19], [20], [21].



Grafik. 2. Zastupljenost posledica saobraćajnih nezgoda u ukupnom broju za period 2010-2022. godine, [19].

Definisanje osnovnih hipoteza istraživanja

Postavljene su dve ključne hipoteze:

-H1-ukupan broj registrovanih traktora i ukupan broj registrovanih gazdinstava imaju različiti uticaj na zavisnu promenjivu koja se odnosi na ukupan broj saobraćajnih nezgoda sa učešćem traktora.

-H2-zastupljenost traktora u ukupnom broju gazdinstava ima različiti uticaj na posledice saobraćajnih nezgoda sa učešćem traktora.

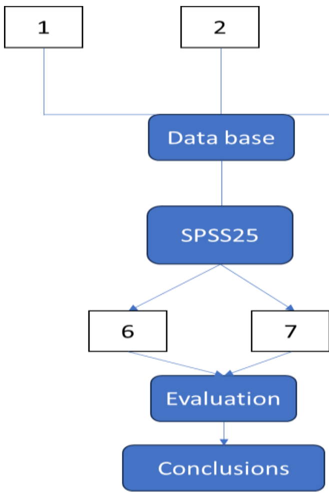
Istraživački model

Za potrebe realizacije istraživanja u ovom radu kreiran je istraživački model prikazan na grafiku 3. Predmetni model je kompleksan i obuhvata različite podatake. Na prvom mestu pod poljem 1 uzeti su statistički podaci o saobraćajnim nezgodama koji se vode kod Agencije za bezbednost saobraćaja Republike Srbije [19]. To su prvenstveno sledeći podaci

- Ukupan broj saobraćajnih nezgoda (Broj SNtr).
- Ukupan broj nezgoda sa poginulima (SN-pog).
- Ukupan broj nezgoda sa materijalnom štetom (SN-mš).
- Ukupan broj nezgoda sa povređenima (SN-pov).

Na drugom mestu pod poljem 2 uzeti su statistički podaci o ukupnom broju registrovanih traktora po opštinama u Republici Srbiji u toku 2022 godine. Predmetni podaci su uzeti iz izveštaja Republičkog zavoda sa statistiku.

Na trećem mestu u polju 3 uzeti su statistički podaci o ukupnom broj registrovanih poljoprivrednih gazdinstava koji se vode na portalu otvorenih podataka [20].



Grafik 3. Istraživački model za analizu podataka
Izvor: Model autora

Svi prethodno navedeni podaci iz polja 1, 2 i 3 su posebna baza podataka. Nakog toga, podaci se eksportuju u program SPSS25.

SPSS25 je statistički paket koji služi za prikupljanje, uređivanje i čuvanje podataka, izvođenje različitih statističkih analiza (deskriptivna statistika, testiranje hipoteza, regresione i korelacione analize, faktorska analiza, ANOVA, multivarijantne tehnike itd.), vizuelizaciju podataka kroz grafikone i tabele, prediktivne analize i modelovanje.

U nastavku se vrši kodiranje podataka i njihova obrada pomoću dve istraživačke tehnike [12].

U polju 6 podaci se analiziraju pomoću Pirsonovog koeficijenta korelacije kako bi se utvrdila statistička povezanost između promenljivih:

- Količnik ukupnog broj registrovanih traktora i ukupnog broja poljoprivrednih gazdinstava po opštinama u Srbiji (KRTG, K – količnik, R – registrovani traktori, T – traktori, G – gazdinstava).
- Ukupan broj nezgoda sa poginulima (SN-pog).
- Ukupan broj nezgoda sa materijalnom štetom (SN-mš).
- Ukupan broj nezgoda sa povređenima (SN-pov).

U polju 7 vrši se analiza podataka pomoću standardne višestruke regresije. Kao zavisna promenljiva uzet je ukupan broj nezgoda sa učešćem traktora (brojSNtr). Kao neprekidne nezavisne promenljive uzete su:

- Ukupan broj registrovanih traktora (Ntraktora)
- Ukupan broj poljoprivrednih gazdinstava (Ngazdinstava).

Osnovni cilj analize podataka u ovom polju odnosio se na to da se utvdi koliko deo varijanse zavisne promenljive je objašnjen varijansom nezavisnih promeljivih.Takođe, cilj se odnosi na utvrđivanje relativnog doprinosa svake nezavisne promenljive i utvrđivanje statističke značajnosti celokupnog modela.

Na osnovu dobijenih rezultata iz polja 6 i 7 vrši se evaluacija dobijenih vrednosti. Na kraju u vezi sa svim dobijenim rezultatima donose se zaključci i predlog mera.

REZULTATI ISTRAŽIVANJA

Posle dobijenih rezultata analize podataka o saobraćajnim nezgodama sa učešćem traktora u ovom delu izvršiće se tumačenje podataka koji su selektovani u polju 6 i 7 istraživačkog modela.

Pirsonov koeficijent korelacije se tumači na sledeći način:

$r \in [-1, 1]$: znak (+/–) daje smer veze, apsolutna vrednost snagu veze.

Orijentiri za jačinu (grubo): 0.00–0.19 vrlo slabo, 0.20–0.39 slabo, 0.40–0.59 umereno, 0.60–0.79 jako, ≥0.80 veoma jako.

r^2 = procenat varijanse jedne promenljive koji je linearno objašnjen drugom.

Obradom podataka iz polja 6 dobijeni su rezultati Pirsonovog koeficijenta korelacije između promeljivih (KRTG,SN-pog, SN-pov i SN-mš) dati u tabeli 1. Na osnovu tih podataka zaključuje se da pozitivan smer korelacije između KRTG i SN-pov i SN-mš i negativan smer korelacije sa SN-pog, (SN-pog - broj poginulih, SN-pov - broj povređenih, SN-mš - nezgode sa materijalnom štetom).

Tabela 1. Rezultati Pirsonovog koeficijenta korelacije između promenljivih

		KRTG	SN-pog	SN-pov	SN-mš
KRTG	Pearson Correlation	1	-.019	.131	.276**
	Sig. (2-tailed)		.819	.114	.001
	N	148	148	148	148
SN-pog	Pearson Correlation	-.019	1	.557**	.326**
	Sig. (2-tailed)	.819		.000	.000
	N	148	149	149	149
SN-pov	Pearson Correlation	.131	.557**	1	.765**
	Sig. (2-tailed)	.114	.000		.000
	N	148	149	149	149
SN-mš	Pearson Correlation	.276**	.326**	.765**	1
	Sig. (2-tailed)	.001	.000	.000	
	N	148	149	149	149

Iz prikazanog se može zaključiti da intenzivnija opremljenost poljoprivrede mehanizacijom (veći broj traktora) ne znači nužno više teških posledica (povrede, smrt), ali znači više ukupnih nezgoda sa materijalnom štetom.

Najveća vrednost korelacije (r 0,276, sig, 0,001) evidentirana je kod nezgoda samo sa materijalnom štetom, a najmanja negativna vrednost (r -0,019, sig. 0.819) kod nezgoda sa poginulim licima. Kod saobraćajnih nezgoda sa povređenim licima dobijena vrednost korelacije iznosi (r 0,131, sig. 0,114).

U tabelama 2a-d dati su rezultati analize podataka primenom standardne višestruke regresione analize. Višestruka regresiona analiza je statistička tehnika koja se koristi kada želimo da ispitamo kako više nezavisnih promenljivih (X1, X2, X3…) zajedno utiču na jednu zavisnu promenljivu (Y).

Standardna (ili simultana) regresija znači da se sve nezavisne promenljive unose u model istovremeno, i na osnovu toga računa se doprinos svake od njih u objašnjenju zavisne promenljive.

R – višestruki koeficijent korelacije (snaga veze između Y i svih X zajedno).

R^2 – objašnjeni procenat varijanse Y pomoću X. Npr. $R^2 = 0{,}40 \rightarrow$ model objašnjava 40% varijanse zavisne promenljive.

Tabela 2a. prikazuje rezultate koeficijenta determinacije koji nam govori kolikim delom varijanse zavisne promenljive je objašnjen istraživački model. U ovom slučaju r2=0.676 što govori da je 67,6% varijanse obuhvaćeno kod nastanka nezgoda sa učešćem vozača traktora. Čak je i korigovana vrednost koeficijenta približno jednaka i iznosi 0,670 kada se uzme u obzir veličina uzorka na kome je vršeno istraživanje.

Tabela 2a. Rezultati standardne višestruke regresije
Rezime modela[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.822[a]	.676	.670	18.08991

U tabeli 2b ANOVA prikazan je segment rezultata koji vrednuje statističku značajnost pokazatelja iz tabele 2a. U tabeli su prikazani rezultati testova nulte hipoteze da je r2 uzorku jednak nuli. Model u ovom slučaju dostiže statističku značajnost (Sig.=0,000), pa je p manje od 0,0005.

Model sa tri nezavisne promenljive značajno predviđa zavisnu promenljivu ($F(3,144) = 100,349$, $p < 0,001$).
Oko 67,6% ukupne varijanse je objašnjeno modelom, što pokazuje visoku prediktivnu snagu. To znači da nezavisne promenljive zajedno imaju vrlo jak i značajan uticaj na zavisnu promenljivu.

Tabela 2b. Rezultati standardne višestruke regresije – ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	98515.882	3	32838.627	100.349	.000[b]
	Residual	47123.268	144	327.245		
	Total	145639.150	147			

Kako bi se predvidelo koja od nezavisnih promenljivih najviše doprinosi predviđanju zavisne promemljive koristimo podatke iz tabele 2c. U koloni za standardne koeficijente potrebno je posmatrati koeficijent Beta. Poseban osvrt uzeli smo na najveći Beta koeficijent od 0,797 koja se odnosi na ukupan broj registrovanih traktora. Značajno manje je zastupljenja vrednost 0,018 koja se odnosi na broj gazdinstava. Na osnovu Beta koeficijenata i Sig. vrednosti može se reći da je N-traktora glavni prediktor u modelu i daje jedinstveni doprinos predikciji zavisne promenljive. Broj gazdinstava nema značajan doprinos i njegova uloga u modelu je minimalna.

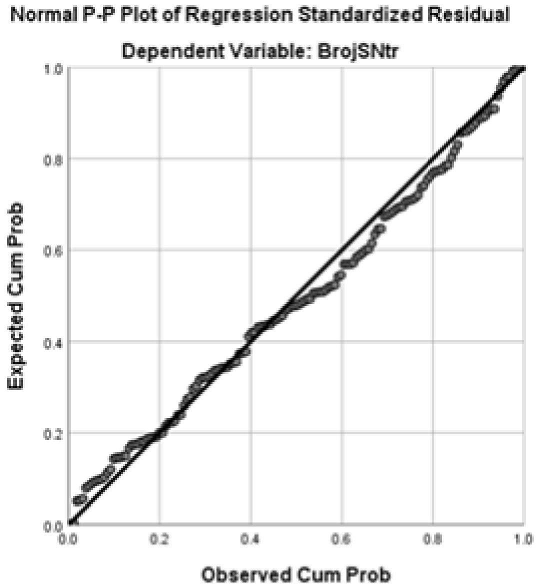
Tabela 2c. Rezultati standardne višestruke regresije-Coeficients

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	6.348	11.683		.543	.588
	N-traktora	.013	.004	.797	3.436	.001
	N-gazdinstava	.000	.003	.018	.079	.937
	KRTG	6.147	13.784	.041	.446	.656

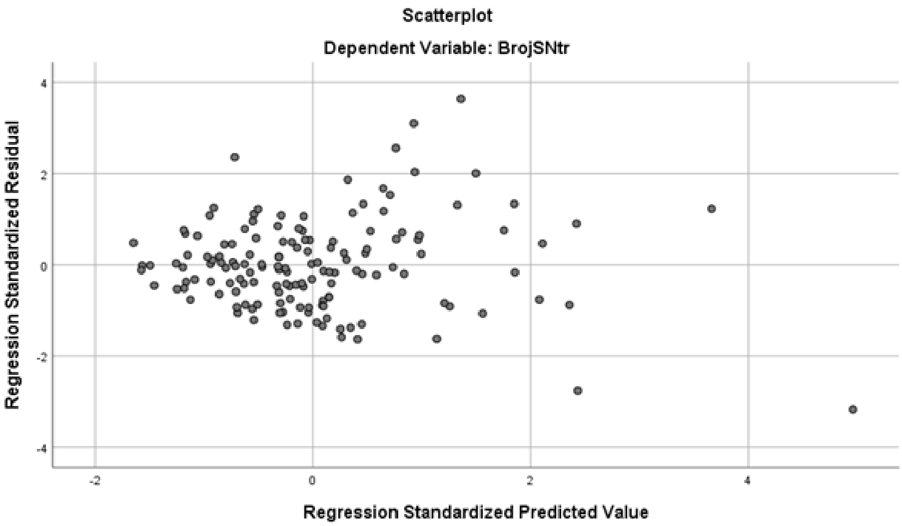
Kao jedan od dodatnog načina za proveru definisanih pretpostavki izrađen su dijagrami u softverskom paketu za statističku analizu podataka (SPSS) i prikazani na slici 2 i 3. Dijagram koji je prikazan nosi naziv Normal P-P Plot of Regression Standardized Residual i odnosi se na zavisnu varijablu označenu kao BrojSNtr.

Na dijagramu se porede posmatrane kumulativne verovatnoće sa očekivanim kumulativnim verovatnoćama kako bi se utvrdilo da li reziduali regresionog modela prate normalnu raspodelu. Na horizontalnoj osi prikazane su posmatrane kumulativne verovatnoće, dok je na vertikalnoj osi prikazana očekivana kumulativna verovatnoća. Obe ose su skalirane u intervalu od 0 do 1. Dijagonala koja prolazi od tačke (0,0) do tačke (1,1) označava idealnu situaciju kada posmatrane i očekivane vrednosti u potpunosti odgovaraju jedna drugoj. Svaka tačka na dijagramu predstavlja standardizovani rezidual, odnosno razliku između posmatrane i predviđene vrednosti, prilagođenu na sredinu nula i standardnu devijaciju jedan.

U ovom slučaju, većina tačaka se nalazi vrlo blizu dijagonale, što ukazuje da reziduali u velikoj meri prate normalnu raspodelu. Manja odstupanja postoje na početku i kraju linije, što se može tumačiti kao uobičajeno blago odstupanje u repovima raspodele. Centralni deo dijagrama pokazuje skoro savršeno podudaranje posmatranih i očekivanih verovatnoća, pa se može zaključiti da nema značajne asimetrije u podacima. Time je pretpostavka o normalnosti reziduala u regresionom modelu uglavnom zadovoljena. To znači da se statistički testovi poput t-testa i F-testa mogu smatrati pouzdanim i da model može davati validne rezultate. U suštini, P-P Plot služi kao vizuelna potvrda normalnosti raspodele reziduala i u ovom slučaju pokazuje da su odstupanja minimalna i da je model adekvatno prilagođen.



Slika 2. Grafikon verovatnoće (P-P) regresije



Slika 3. Dijagram rasturanja reziduala

Dijagram (Slika 3.), jasno prikazuje raspored tačaka oko horizontalne ose koja predstavlja nultu vrednost standardizovanih reziduala. Većina tačaka nalazi se u intervalu između -2 i 2, što ukazuje na to da najveći deo reziduala nema ekstremna odstupanja. To znači da model uglavnom dobro predviđa vrednosti zavisne varijable. Međutim, primećuje se i nekoliko tačaka koje odstupaju iznad vrednosti 2 i ispod vrednosti -2, pa čak i do 4, što ukazuje na postojanje određenih outliera ili posmatranja sa neuobičajeno visokim greškama. Takve vrednosti mogu značajno uticati na model i zahtevaju pažljivije razmatranje. Ako su ti podaci rezultat greške u merenju ili unosu, trebalo bi ih proveriti, a ako su stvarne ekstremne vrednosti, onda predstavljaju važne informacije koje upućuju na specifične slučajeve.

Raspored tačaka na dijagramu nije potpuno slučajan. Uočen je određeni obrazac u kojem reziduali sa porastom predviđenih vrednosti pokazuju veću varijabilnost. U centralnom delu dijagrama, kada su predviđene vrednosti bliže nuli, reziduali su grupisani gušće i pokazuju manja odstupanja. Kako predviđene vrednosti rastu, primećuje se da reziduali postaju razuđeniji i da odstupanja rastu. Ovaj obrazac ukazuje na potencijalni problem heteroskedastičnosti, odnosno situacije kada varijansa reziduala nije konstantna duž skale predviđenih vrednosti. Kada postoji heteroskedastičnost, regresioni model gubi efikasnost jer standardne greške koeficijenata mogu biti pogrešno procenjene, što dovodi do nepouzdanih statističkih testova i zaključaka.

U dobro specificiranom regresionom modelu očekuje se da tačke na scatterplotu budu nasumično rasute oko horizontalne ose bez prepoznatljivog obrasca. Ako bi tačke formirale paraboličan, linearni ili neki drugi vidljiv oblik, to bi ukazivalo da model nije dobro specificiran i da možda nedostaju neki prediktori ili da bi trebalo razmotriti transformaciju varijabli. U ovom slučaju, dijagram pokazuje određeno širenje oblaka tačaka kako se povećavaju predviđene vrednosti, što može sugerisati da zavisna varijabla nije u potpunosti linearno povezana sa nezavisnim varijablama.

Moguće je da bi neka transformacija zavisne varijable, na primer logaritamska, kvadratna ili kvadratni koren, poboljšala prilagođenost modela i obezbedila stabilniju varijansu reziduala.

Prisustvo nekoliko ekstremnih tačaka, posebno onih sa rezidualima većim od 3 ili manjim od -3, može ukazivati na uticajne posmatrače. Takvi posmatrači imaju disproporcionalan uticaj na procenu regresionih koeficijenata i mogu promeniti nagib ili intercept regresione linije. Da bi se procenilo da li su ove tačke zaista problematične, neophodno je analizirati dodatne statistike, poput Cookovog rastojanja ili Mahalanobisovih udaljenosti. Ako se potvrdi da su posmatranja zaista uticajna, treba doneti odluku da li ih treba zadržati u analizi kao reprezentativne ekstremne vrednosti ili ih ukloniti ukoliko predstavljaju grešku.

Važna pretpostavka regresione analize jeste normalna distribucija reziduala, što je delimično potvrđeno P-P plotom iz prethodnog dijagrama. Međutim, scatterplot pruža dodatnu potvrdu ili osporavanje pretpostavke o linearnosti i homogenosti varijanse. Ako reziduali rastu i opadaju u nekom pravilnom obrascu, to znači da model ne uspeva da u potpunosti uhvati vezu između zavisne i nezavisnih varijabli. U ovom slučaju, primećuje se blaga tendencija da se reziduali povećavaju kod viših predviđenih vrednosti, što može značiti da zavisna varijabla ima širu disperziju pri većim vrednostima. To je klasičan znak heteroskedastičnosti, koji bi mogao da se reši transformacijom podataka ili korišćenjem robusne regresije koja nije osetljiva na promenu varijanse.

Raspored tačaka u centralnom delu dijagrama daje prilično dobru sliku. Oko horizontalne linije nula primećuje se veliki broj tačaka, što znači da model za većinu posmatranja daje relativno tačne prognoze. To je pozitivan znak jer pokazuje da model funkcioniše dobro za tipične vrednosti podataka. Problemi se javljaju tek na ekstremima gde se vidi veća varijabilnost. To je uobičajena pojava u mnogim regresionim modelima, jer ekstremi uvek nose veći rizik od odstupanja. U statističkoj praksi, cilj je da se model optimizuje tako da dobro funkcioniše za većinu posmatranja, dok ekstremi zahtevaju posebnu interpretaciju i pažnju.

Jedna od ključnih funkcija scatterplota reziduala jeste otkrivanje eventualnih nelinearnosti. Ako bi se u ovom dijagramu uočio zakrivljen obrazac, recimo parabolični oblik oblaka tačaka, to bi bio dokaz da linearni model nije adekvatan i da bi trebalo uvesti polinomske ili interakcione termine u model. Ovde obrazac nije toliko jasan, ali postoji blagi trend povećanja raspona reziduala sa rastom predviđenih vrednosti, što može ukazivati na to da model ne objašnjava najbolje ponašanje zavisne varijable u višim intervalima. To ne znači da je model potpuno neupotrebljiv, već da se može dodatno unaprediti uključivanjem dodatnih prediktora ili transformacijom postojeće zavisne varijable.

Dijagram takođe pokazuje da je raspodela reziduala asimetrična. Naime, postoji više tačaka iznad nulte linije nego ispod, posebno u desnom delu grafikona. To može značiti da model ima tendenciju da potcenjuje stvarne vrednosti u višem rasponu zavisne varijable. Drugim rečima, kada su predviđene vrednosti veće, stvarne vrednosti imaju tendenciju da budu još veće nego što model predviđa. Ovo je važan uvid jer ukazuje na sistematsku grešku modela.

Ako se ovakav obrazac potvrdi, model bi mogao da se unapredi uvođenjem dodatnih varijabli koje bolje objašnjavaju ponašanje zavisne varijable u višem rasponu.

U praktičnoj primeni, ovakvi rezultati ukazuju analitičaru da iako model daje korektne rezultate za većinu posmatranja, on ipak ne uspeva da u potpunosti obuhvati sve varijacije u podacima. To može biti posledica izostavljenih varijabli, nelinearnih odnosa ili prisustva autokorelacije u podacima. Ako se model koristi u prediktivne svrhe, važno je imati u vidu da predikcije mogu biti manje pouzdane u ekstremnim vrednostima i da ih treba tumačiti s rezervom.

Zaključak koji se može izvesti iz ovog scatterplota jeste da model pokazuje relativno dobru stabilnost u centralnim vrednostima, ali pokazuje i znake heteroskedastičnosti i nekoliko outliera koji mogu uticati na tačnost procene. Za potpuniju potvrdu ovih nalaza treba uraditi dodatne testove poput Breusch-Paganovog testa za heteroskedastičnost ili Cookovog rastojanja za uticajne tačke. Ako se potvrdi prisustvo problema, mogu se primeniti odgovarajuće korekcije u modeliranju.

U suštini, scatterplot jasno pokazuje da model nije potpuno savršen, ali je funkcionalan za osnovne potrebe. Uz dodatne dorade, kao što su transformacija podataka ili dodavanje prediktora, njegova preciznost i stabilnost mogle bi se značajno poboljšati.

DISKUSIJA REZULTATA

Analizom podataka o saobraćajnim nezgodama sa učešćem traktora svakako se i za teritoririju Republike Srbije može zaključiti da je ovaj tip nezgoda značajno zastupljen. Ovakav zaključak se svakako poklapa sa rezultatima drugih istraživanja [3], [24], [25].

Po pitanju ažurnosti i dostupnosti baza podataka o saobraćajnim nezgodama sa učešćem traktora, za Republiku Srbiju može se definisati pozitivan zaključak i dostupnost podataka o nezgodama [19].

Terminilogija kojom se definišu traktori u Republici Srbiji usklađena je sa važećim terminima na nivou EU [22]. Predmetna terminologija ugrađena je u skladu sa važećim Zakonom o bezbednosti saobraćaja na putevima i pratećim Pravilnicima.

Ukupan broj traktora u poljoprivrednim gazdinstvima nije na značajno velikom nivou. Međutim, kada smo tu zastupljenost postavili u korelaciju sa saobraćajnim nezgodama sa povređenim licima, saobraćajnim nezgodama sa materijalnom štetom i saobraćajnim nezgodama sa poginulim licima došlo se do zaključka da postoji različit uticaj na posledice saobraćajnih nezgoda sa traktorima. To je posebno utvrđeno za saobraćajne nezgode sa poginulim licima gde je dobijena vrednost Pirsonov koeficijent korelacije (-0,019, r 0.819). Hipoteza H2 se odnosi na očekivanje da postoji statistički značajna povezanost između količnika registrovanih traktora po gazdinstvima (KRTG) i pokazatelja saobraćajnih nezgoda (SN-pog, SN-pov, SN-mš). Drugim rečima, pretpostavka je bila da stepen mehanizovanosti poljoprivrede utiče na obrasce saobraćajnih nezgoda u kojima učestvuju traktori. Na osnovu različitih vrednosti i pravaca Pirsonovog koeficijenta korelacije može se zaključiti da hipoteza H2 je potvrđena – postoji značajna i različito usmerena povezanost između mehanizovanosti (KRTG) i strukture saobraćajnih nezgoda sa traktorima.

Testiranjem hipoteze H2 pomoću metode standardne višestruke regresione analize analizirano je koja od nezavisnih promenljivih najviše doprinosi predikciji zavisne promenljive. Zaključeno je da promenljiva broj traktora daje jedinstveni doprinos predikciji zavisne promenljive. Rezultati Beta koeficijenta su pokazali da promenljiva broj gazdinstava ne daje jedinstveni doprinos predikciji zavisne promenljive. Na ovaj način dokazana je hipoteza H2.

ZAKLJUČAK

Analiza podataka pokazuje da je ukupan broj registrovanih traktora glavni prediktor broja saobraćajnih nezgoda sa učešćem traktora u Republici Srbiji, dok ukupan broj poljoprivrednih gazdinstava nema značajan doprinos. Veći broj traktora povezan je pre svega sa nezgodama koje izazivaju materijalnu štetu, dok broj nezgoda sa povredama i poginulima nije značajno zavisan od intenziteta opremljenosti mehanizacijom.

Model višestruke regresije objašnjava 67,6% varijanse zavisne promenljive, što ukazuje na njegovu visoku prediktivnu snagu, a analiza reziduala potvrđuje da su osnovne pretpostavke modela uglavnom zadovoljene.

Rezultati istraživanja naglašavaju potrebu za kontinuiranim praćenjem saobraćajnih nezgoda i unapređenjem bezbednosnih mera za učešće traktora u javnom saobraćaju Republike Srbije..

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INTEGRATED MODEL FOR THE ASSESSMENT OF THE SUSTAINABILITY OF THE SAFETY OF TRACTOR MOVEMENTS IN PUBLIC TRANSPORT IN THE REPUBLIC OF SERBIA

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Abstract. Tractors represent a very important category of public traffic participants. In addition, they are a key factor in the daily work and development of agricultural activities worldwide. During the performance of their tasks, tractors are regularly present on both public and rural roads.In this context, tractors are significantly involved in traffic accidents on roads, as well as in unfortunate events occurring off public roads. The consequences of such accidents and incidents are often severe.

Numerous studies and research have been conducted so far, analyzing the causes and circumstances of tractor-related traffic accidents. Several key factors have been identified as contributing to the occurrence and outcomes of these accidents.

In this study, two working hypotheses were formulated and subsequently investigated and tested. As part of the research, a model was developed to analyze the impact of the number of registered tractors relative to the number of registered agricultural holdings on the occurrence of tractor-related accidents and their consequences, across municipalities in the Republic of Serbia.

The model examined the contribution of independent variables — the number of registered tractors and the number of agricultural holdings per municipality — to the dependent variable, which was the total number of traffic accidents involving tractors.

Using statistical data and applying standard multiple regression analysis in SPSS25, a statistically significant relationship was found between the observed variables.

It was concluded that the number of registered tractors has a different impact compared to the number of agricultural holdings, and that the proportion of tractors within the total number of holdings has a specific influence on the consequences of public traffic accidents involving tractors.

Key words: *Tractors, traffic safety, traffic accidents.*

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