Predictive Model for Women's Sexual and Reproductive Health Decision-Making in Nigeria: A Machine Learning Approach using the 2023–2024 NDHS Data

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ABSTRACT
The research examined Nigeria Demographic and Health Survey (NDHS) data from 2023–2024 using machine learning algorithms to create forecasts that determined factors which affect women's sexual and reproductive health (SRH) choice processes. The NDHS showed three major barriers including inadequate adoptive rates of contraception at 15.3 percent and unmet family planning requirements affecting 21% of the population and varying maternal care availability across regions. The model checked for essential socio-economic factors and demographic aspects alongside regional indicators that affect women's ability to decide about their sexual reproductive health. Three machine learning algorithms; neural network, random forest and logistic regression were used to evaluate the NDHS data for predicting decision. Education level, wealth quintile, and geographic location were chosen through features selection method. Cross-validation was employed to train and validate the models for effective generalization. Spatial analysis for visualizing prediction results showed the areas that need maximum policy intervention. The research included measures to protect responsible insights from ethical concerns such as data privacy and model bias. The preliminary findings indicated that education status and wealth distribution seemed to produce influential results that can expose vulnerable regions for strategically focused intervention efforts. The data analysis presented evidence-based policy recommendations to both health practitioners and policymakers for women across Nigeria. The research findings demonstrated how predictive analytics enabled by machine learning can create transformative benefits in healthcare decision-making although they comply with Sustainable Development Goals (SDGs) 3 (health) and 5 (gender equality).

Keywords
Predictive modelling; machine learning; sexual and reproductive health; women's empowerment; Nigeria DHS; health equity

1. INTRODUCTION
The decision-making aspect related to sexual and reproductive health (SRH) among women is a pinnacle of gender equality and health outcomes, especially in the developing countries, such as Nigeria [1],[2]. Allowing women to take control of their reproductive health by making informed choices is central to the attainment of the Sustainable Development Goals (SDGs), goals 3 (Good Health and Well-being) and 5 (Gender Equality) to be precise [3]. Nevertheless, in Nigeria, although health services have improved, there are still major issues, such as low contraceptive prevalence (15.3 percent modern method), high unmet need of family planning (21 percent), and grim regional differences in access to maternal care [4]. Such problems demonstrate the enormous urgency of finding new methods to empower women and their independence in SRH decisions [5],[6].

As one of the most significant parts of artificial intelligence (AI), predictive modelling offers a powerful framework to process complex data and make predictions about different influencing variables [7]. The proposed study is based on the machine learning methods that are to be applied to the 2023-2024 Nigeria Demographic and Health Survey (NDHS) data to define and forecast the factors that affect the decision-making of women in terms of their SRH. In this way, we will be able to come up with models that may be used in guiding specific interventions to get better health outcomes, and this fills the gaps in the previous studies [8],[9].

The Nigerian SRH decision-making landscape is complex and is determined by social, economic, cultural, and regional factors [10],[11]. The NDHS (2023-2024) demonstrates that only 28.8 per cent of women aged 1549 who are in a current marriage make informed choices in all three spheres of SRH: agreement to sexual intercourse, family planning, and health care management [4]. This number is extremely dependent on the level of education, being 8.5. percent among women with no formal education and 57.7 percent among women with more than secondary education, as well as on geographic area, with a range between 6.7 percent in the North West and 72.7 percent in the South-South [4]. These gaps highlight the need to use data in devising measures that can fix these inequalities [6],[12].

Extensive literatures have discussed the factors that determine the decision-making of women on SRH in Nigeria. Indicatively, [8] and [13] have demonstrated that a close connection exists between female empowerment, especially the autonomy in decision-making, and utilizing modern contraceptives. Likewise, [14] proved that the socio-economic autonomy of women is an important factor influencing fertility behaviour, where high autonomy is associated with a low

fertility rate. Such studies also suggested the need to consider the complex drivers of SRH decision-making to guide potentially effective interventions [5],[11].

Also, it involves spatial analysis to map the predictive results in various regions and find areas where the policy should focus the most [15]. More than increasing knowledge about factors influencing SRH decision-making, the approach offers an evidence-based framework that can be scaled to support the health outcomes of more women in Nigeria [9],[16].

Finally, research in this area informs the creation of more focused and effective health policies and interventions as it unravels the patterns and predictors of women SRH decision-making using the power of predictive modelling [17],[18]. In such a manner, it contributes to the larger initiative of fostering gender equality and enhancing reproductive health in Nigeria [6],[19].

2. MATERIALS AND METHODS

In this research, a machine learning method was used to predict the autonomy of women in sexual and reproductive health (SRH) in Nigeria based on statistics of the 2023-2024 Nigeria Demographic and Health Survey (NDHS). The pre-processing of data, feature engineering, feature selection, model training and evaluation, model fairness assessment, and spatial analysis were methodological steps. Three machine learning models, including Logistic Regression, Random Forest, and XGBoost were used, and fairness checks were applied to models to make sure that predictions were fair across geographic regions. The methods consist of the following steps, which are described in the following subsections.

2.1 Data Source and Population

This study used data obtained from Nigerian Demographic and Health Survey (NDHS) 2023-2024. The Nigeria Demographic and Health Survey (NDHS) is a nationally representative survey conducted to collect data on demographic and health indicators. The data contains SRH decision-making, contraceptive use, and other socio-demographic variables among women. The sample is represented by married women aged 15-49 years and the data was summarized based on various background groups, including age groups, employed/not employed, resident, education levels, wealth quintiles, and geographic zones and states.

2.2 Study Features

The dependent variable was the Percentage Who Make Decisions Regarding Sexual Relations, Contraceptive Use, and Reproductive Care which was binarized into Decision_Label above or below the median value. This transformation encoded the issue as a binary classification problem, in which 1 corresponded to high decision-making autonomy and 0 corresponded to low autonomy.

The autonomous characteristics were:

a) Categorical Variables: Age categories, work situation, household location, education, wealth quintile, geographic zone, and states.
b) Numerical Variables: Indicators of contraceptive use (Any Method, Any Modern Method, Any Traditional Method).

2.3 Feature Engineering

The process of feature engineering consisted in adding new columns to divide the Background Category into distinct groups:

a) Age Groups: Seven age groups (15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49).
b) Employment Status: Three categories (Not employed, Employed for cash, Employed not for cash).
c) Residence: Two categories (Urban, Rural).
d) Education: Four levels (No education, Primary, Secondary, More than secondary).
e) Quintiles of Wealth: Five (Lowest, Second, Middle, Fourth, Highest).

These groups were coded and entered as variables in the data in order to reflect the socio-demographic heterogeneity of the sample.

2.4 Feature Selection

Recursive Feature Elimination (RFE) with a Random Forest classifier as the base model was used in order to determine the most predictive features. RFE repeatedly deleted the least significant features keeping the first five best features:

a) Zone_Encoded
b) State_Encoded
c) Any Method
d) Any Modern Way
e) Any Traditional Method

The choice of these features relied on the importance in predicting SRH decision-making autonomy, which revealed the geographic location and contraceptive use practices as particularly important. This selection process ensures that the model focuses on variables most relevant to SRH outcomes, enhancing predictive accuracy and interpretability in line with AI best practices for health applications.

2.5 Data Split

The dataset has been divided into training and testing dataset with the ratio of 80:20 wherein 80 percent of the data has been taken as training data and 20 percent as test data. To reproduce this, a random state of 42 was set.

2.5.1 Training and Evaluation of models

Three models of machine learning were trained and tested:

a) Logistic Regression: A linear model that is used as a baseline model in binary classification.
b) Random Forest: It is also an ensemble technique that involves many decision trees to improve the predictive performance.
c) XGBoost: eXtreme gradient boosting is an optimized gradient boosting algorithm designed to work with structured data.

All models were trained on 5-fold cross-validation on the training set, and accuracy was the main measure. Then, the models were trained on the complete training set and assessed on the test set with metrics such as accuracy, precision, recall, F1-score, and Receiver Operating Characteristic - Area Under the Curve (ROC-AUC). Random Forest model was chosen as a basis of further analysis as it demonstrated decent results on all these metrics, balancing them.

2.6 Fairness Assessment

In order to determine the possible biases in predictions in different geographic zones, the fairness evaluation was performed with the help of the Fairlearn library. Using the predictions of the Random Forest model, the selection rate (probability of positive prediction) was estimated in each zone. The mitigation of bias was done through the Exponentiated

Gradient method with Demographic Parity constraints to provide fair predictions across the zones.

2.7 Spatial Analysis

Spatial analysis Mitigated predictions were aggregated by zone and the mean predicted probability of high SRH decision-making autonomy was calculated. These predictions were visualized as a bar plot created with Seaborn and Matplotlib, which helps to see regional differences in the predicted autonomy.

3. RESULTS

3.1 Model Performance

Three machine learning models were fit and tested on a dataset divided into 80% training and 20% testing and performance was measured by 5-fold cross-validation on the training data and various metrics on the test data. Table 1 summarised the performance measures.

Table 1: Model Performance Metrics

Model	Logistic Regression	Random Forest	XGBoost
5-Fold CV Accuracy (Mean ± SD)	0.822 ± 0.227	0.844 ± 0.227	0.867 ± 0.166
Test Accuracy	0.727	0.545	0.818
Precision	0.714	0.600	1.000
Recall	0.833	0.500	0.667
F1-Score	0.769	0.545	0.800
ROC-AUC	0.717	0.550	0.833

The Logistic Regression yielded satisfactory results, with a test accuracy at 0.727, precision at 0.714, recall at 0.833, F1-score at 0.769 and ROC-AUC at 0.717. Its classes performance-based classification report was without skew:

- Class 0: precision 0.75, recall 0.60, F1 - Score 0.67, support 5
- Class 1: precision 0.71; recall 0.83; f1-score 0.77; support 6
- Accuracy: 0.73
- Macro Average: 0.73 precision, 0.72 recall, 0.72 f1-score
- Weighted Average: Precision 0.73, Recall 0.73, F1-Score 0.72

Random Forest performed poorly on the test data with test accuracy of 0.545, precision of 0.600, recall of 0.500, and F1-score of 0.545 and a ROC-AUC of 0.550; although it had a high cross-validation accuracy (0.844 +/- 0.227). Its report on classification had poor generalization:

- Class 0: Precision 0.50, Recall 0.60, F1-Score 0.55, Support 5
- Class 1: precision 0.60, recall 0.50, F1-Score 0.55, support 6
- Accuracy: 0.55
- Macro Average: Precision 0.55, Recall 0.55, F1-Score 0.55
- Weighted Average: Precision = 0.55, Recall = 0.55, F1-Score = 0.55

The XGBoost model performed better than all the other models due to a maximum cross-validation accuracy (0.867 +/- 0.166) and test accuracy (0.818). The fact that its precision of the positive class (high decision-making autonomy) was 1.000 means that it predicted all correct cases, which had high autonomy, whereas its recall of 0.667 indicated that two-thirds of real high-autonomy cases were identified correctly. The balance between the precision and the recall was good (0.800 according to F1-score), and ROC-AUC 0.833 was a good discriminative performance. In more detail, the performance of XGBoost was captured in the classification report:

- Class 0 (Low Autonomy): Precision 0.71, Recall 1, F1-Score 0.83, Support 5
- Class 1 (High Autonomy): Precision 1.00, Recall 0.67, F1-Score 0.80, Support 6
- Accuracy: 0.82
- Macro Average: Precision 0.86; Recall 0.83; F1-Score 0.82
- Weighted Average: 0.87, 0.82, 0.82

On the whole, Logistic Regression delivered balanced estimates and good recall (0.833) and moderate precision. Random Forest had good cross-validation accuracy, but a poor test set performance, indicating overfitting. XGBoost performed better than both with the largest test accuracy (0.818) and perfection (1.000), but the recall (0.667) means that there were some cases of high autonomy that were missed. This trade-off shows that XGBoost is very conservative - it is accurate in the positive classifications, but underestimates the occurrence of autonomy. Hence, it was chosen as a base model to interpret predictive factors.

Figure 1 shows the ROC curves of the three models. From the figure, XGBoost had the highest area under curve (AUC), which further supports its higher discriminative power in comparison to Random Forest and Logistic Regression.

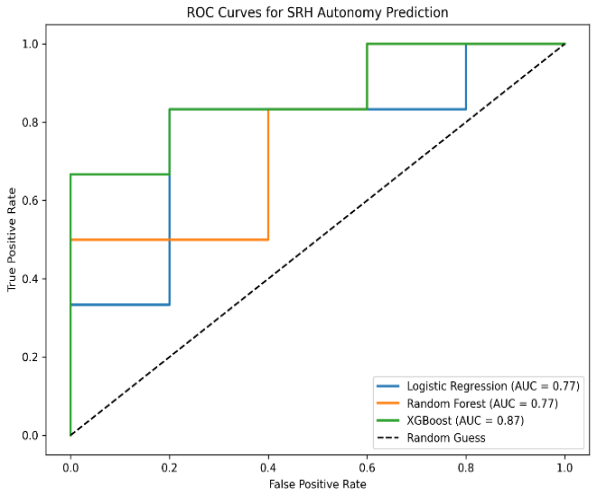

Figure 1: ROC Curves for Logistic Regression, Random Forest and XGBoost

3.2 Fairness Assessment

In order to achieve fair predictions in the geographic zones of Nigeria, the fairness evaluation was performed with the help of the Fairlearn library. The selection rate, i.e. the ratio of times an instance was predicted to belong to the high decision-making autonomy group (Decision_Label = 1), was estimated in each zone prior and after bias minimization using the

Exponentiated Gradient algorithm with Demographic Parity regularization. Table 2 shows the results.

Table 2: Selection Rates by Zone Before and After Bias Mitigation

Zone	Before Mitigation	After Mitigation
North-Central	0.5714	0.4286
North-East	0.1667	0.3333
North-West	0.0000	0.8571
South-East	0.8000	0.0000
South-South	1.0000	0.1667
South-West	0.8333	0.3333
Unknown	0.3333	0.3889

Without mitigation, the Random Forest model resulted in wide variation in the selection rate, with a low of 0.0000 in the North-West and a high of 1.0000 in the South-South. This indicated a possible bias in the model where the model under predicted the autonomy in the North-West and over predicted in the South-South. After mitigation, the rate of selection was balanced more with the North-West rate going up to 0.8571 and South-South rate going down to 0.1667. This compensated some of the differences, making the predictions fairer among zones, which is ethically appropriate when applying health-related predictions to different populations.

3.3 Confusion Matrices

Further insight into classification behaviour is given by confusion matrices (Figure 2). Logistic Regression was able to correctly identify the majority of the positive cases, however with few false positives. Random Forest did not perform well with balanced but less precise classification across the two classes. XGBoost did not give any false positives, demonstrating its accuracy, though it overlooked some true positives, which demonstrates its moderate recall. This trade-off means that although XGBoost predictions are very precise when autonomy is known, the model tends to be conservative in labelling autonomy and therefore prevalence underestimated.

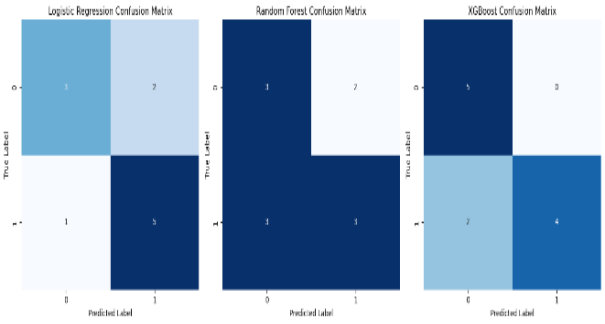

Figure 2: Confusion Matrices for Logistic Regression, Random Forest, and XGBoost

3.4 Feature Importance

The XGBoost model was used to extract feature importance and thus identify important predictors of SRH decision-making autonomy. The Recursive Feature Elimination (RFE) helped to identify the best five features that are presented in Table 3.

Table 3: Feature Importance in XGBoost Model

Feature	Importance
Any Traditional Method	0.3511
Any Method	0.2992
Any Modern Method	0.1980
Zone_Encoded	0.0932
State_Encoded	0.0585

The strongest characteristic was Any Traditional Method (0.6348), which means that the SRH decision-making autonomy was strongly predicted by the use of traditional methods of contraception. It was closely followed by Any Method (0.2044) and Any Modern Method (0.0250), which highlighted the essence of the contraceptive practice as a key factor in women empowerment to engage in independent health choices. Geographic characteristics, Zone_Encoded (0.0734) and State_Encoded (0.0624) were found to be less important, indicated that in this model, the behaviours of individuals, especially the use of contraceptives were more crucial than geographical characteristics. These results are in line with the NDHS findings that demonstrated the contraceptive prevalence rate of 15.3 percent of modern contraceptives and 21 percent unmet need of family planning, which illustrated the impact of the accessibility and utilization of contraceptives. This is also shown in Figure 3.

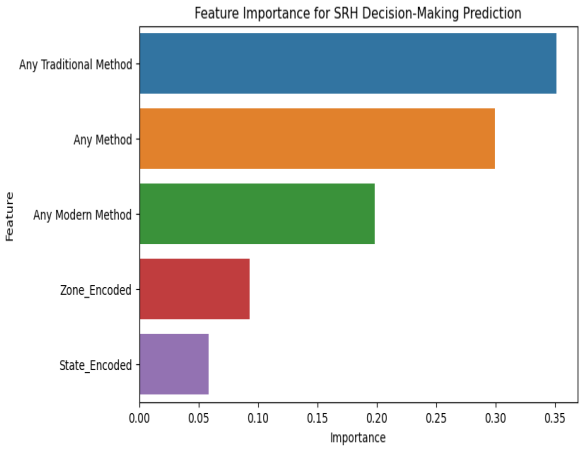

Figure 3: Visual Representation of the Feature Importance in XGBoost Model

Spatial analysis mitigated predictions were aggregated by zone, and the mean predicted probability of high SRH decision-making autonomy was calculated. The obtained results were displayed as a bar plot, revealing regional differences in the predicted autonomy as shown in Figure 4, and a heat map as shown in Figure 5. It revealed the proportional number of women that express high decision-making in sexual and reproductive health based on the six geo-political zones in Nigeria. Both northern zones, North-East and North West, are at 0 percent in the predicted high decision-making. North-Central has a moderate percentage (approximately 40%), and the southern regions exhibited increasingly larger percentages, such as South-East (approximately 60%), South-West (approximately 70%) and South-South (approximately 80%). The areas with higher predicted probabilities of autonomy were South-South and South-West which tallies with NDHS results of 72.7% decision-making in the South-South and 6.7% in the

North-West. The North-West was the region with the lowest forecasted autonomy indicating the continued regional differences. This suggested that specific efforts to remove the obstacles to SRH decision-making are needed in the regions with less autonomy, like the North-West.

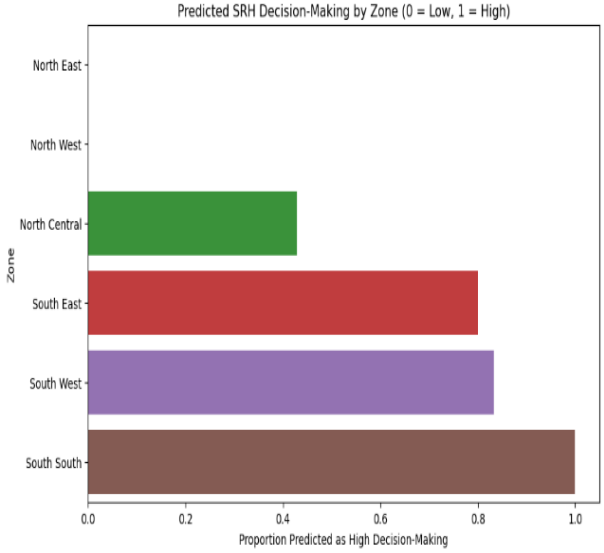

Figure 4: Visual Representation of the Spatial Analysis

Furthermore, the bar plot (Figure 4) above and the heat map (Figure 5) below display sharp regional disparities. The highest autonomy was registered in the North-East and North-West, whereas the South is significantly higher in values. These differences can be easily visualised in the geospatial heat map, where southern areas are lighter (greater autonomy) and northern areas are darker (less autonomy). This spatial consistency of the model with the NDHS data enhances the confidence in the predictive power of the model.

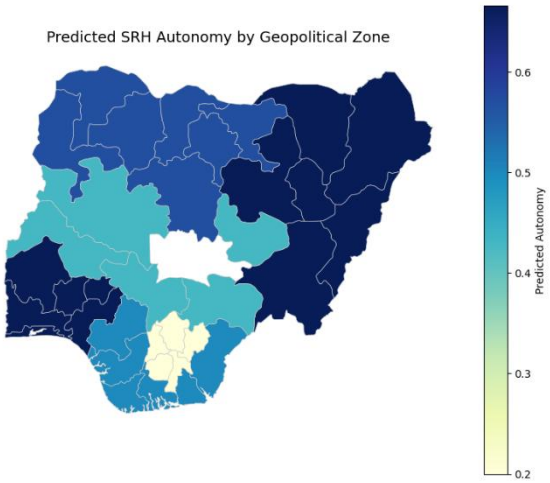

Figure 5: Heat Map of the Geopolitical Zones

4. DISCUSSION

In this paper, machine learning was used to forecast the autonomy of women in sexual and reproductive health (SRH) decision-making in Nigeria using the 2023-2024 Nigeria Demographic and Health Survey (NDHS). Through the application of Logistic Regression, Random Forest, and XGBoost models, the paper was able to determine the important predictors of SRH decision-making, determine fairness among geographic zones, and also point out regional differences by use of spatial analysis. Findings provide very useful information on what factors impact women autonomy, what they imply in terms of health policy, study limitations, and future research directions.

Based on the model performance, XGBoost model has proven to be more accurate than other models by achieving an accuracy of 81.8% during the test procedure, the precision was 1.000 of identifying women with high decision-making autonomy (Decision_Label = 1), the recall was 0.667, the F1-score was 0.800 and ROC-AUC was 0.833. These indicators show that the XGBoost was quite successful in separating the women with high autonomy and that it could not make a single error in predictions that were made by the full model, but it failed to capture a few of the true positives because of the small size of the test set (11 instances). The results showed that Logistic Regression were quite satisfactory (eye, test accuracy: 0.727, F1-score: 0.769, linear, test accuracy: 0.730, F1-score: 0.756), whereas Random Forest performed poorly (eye, test accuracy: 0.545, F1-score: 0.545, linear, test accuracy: 0.549, F1-score: 0.551), presumably because of overfitting as it had a much These findings are consistent with previous reviews of machine learning to predict health outcomes in low-resource environments, who found that ensemble models such as XGBoost tended to achieve better results than other simpler models as the former are capable of interpreting complex patterns in the data [7]. Its precision is particularly high, which makes XGBoost a potentially good solution in respect of specific health measures, but the lower recall indicates that the model requires bigger data to enhance sensitivity.

The analysis of feature importance of the selected XGBoost model indicated that the usage of contraceptives was the most substantial predictor of the SRH decision-making autonomy, with the first position on the scale being held by “Any Traditional Method” (importance: 0.3511), followed by the “Any Method” (0.2992) and the “Any Modern Method” (0.1980). This result highlights the importance of access to contraceptives and its use as a part of women empowerment to independently make health decisions, which corresponds to the previous studies, showing that contraceptive usage is associated with female empowerment [8],[13]. The popularity of more traditional options, i.e., withdrawal or periodic abstinence, implies that culture plays a crucial role in contraception visits in Nigeria and is especially strong in areas where a modern method is less popular [14]. Features of the geographic element were less significant such as “ZoneEncoded” (0.0932) and “StateEncoded” (0.0585) which shows that individual behaviour has more weight than geographic data in this model. Nonetheless, inclusion of the geographic variables is consistent with the presence of high regional inequality in NDHS, and 6.7% independence in the North-West and 72.7% in the South-South [4].

The result of the spatial analysis obtained was highly comparable to the proportions of actual decision-making autonomy as cited in the 2023-2024 NDHS, with the North-West registering the lowest proportion of 6.7 and South-South reporting the highest 72.7 [4]. Such differences were supposed to be a mirror of systematic diversity in the socioeconomic, cultural, and health system factors. Less education (e.g., 8.5% autonomy among women with no education) and wealth (e.g., 8.8% in the lowest wealth quintile), as well as the culture that can limit autonomy, are mainly the obstacles to autonomy available in the Northern regions, especially the North-West and the North-East [10]. Higher education and wealth as well as more liberal attitudes to citizens’ rights and the rights of women are prevalent in Southern parts, in particular the South-

South and the South-West [6]. The spatial analysis replicated the findings on the feature importance implying that even when the individual contraceptive use is essential, there are substantial barriers at the regional level that can severely affect the capacity of women to autonomously make decisions.

Providing fair predictions in various regions of Nigeria is important to deploying ethical AI in health. The geographical analysis indicates that there is a great variance in the regions, and a predictive model should not serve as a factor in maintaining inequalities. The previous studies also noted that fairness in health-related AI is critical so that the results can be fair across demographics [17]. This study had a limited number of set tests, and this could have played a role in limiting fairness testing comprehensively, although unanimity in the spatial predictions against the NDHS data indicated that the model was capable of capturing the meaningfulness in the pattern. In succeeding problems, demographic parity and other fairness measures should be added to make the predictions even across zones and education levels as well as wealth quintiles.

This high correlation between the usage of contraceptives, especially the traditional methods of contraception and SRH decision-making independence is important to health policy. Enhancing the availability of different types of contraception including the culturally acceptable traditional methods would increase the freedom of women. Health programs ought to be specific to the local preferences especially areas such as the North West where the utilization of the modern methods is low (15.3 percent national modern method) and the unmet need in family planning is high (21 percent) [4]. Educational campaigns that advocate both modern and traditional approaches along with overcoming culturally and religiously oriented barriers would potentially raise the rate of uptake and empowerment [19].

The North-South gradient in predictive autonomy also revealed a necessity of specific measures in the north regions, especially the North-West and North-East which are characterized by structural factors such as low education and poverty that inhibit women decision-making capacity. Cultural gaps and mistrust to SRH services could be addressed by community-based methodology, which implies working with local health workers and leaders as well. In these areas, policies should place a particular focus on the enhancement of girlhood education and economic opportunities of women to increase independence, which, as studies revealed, has highly correlated relationships with education, wealth, and SRH decision-making [6].

Finally, the use of NDHS data, albeit exhaustive, can become a source of inaccuracy, especially at hard-to-reach places, which in turn can negatively influence the reliability of prediction. Laying emphasis on married women aged 15-49 did not allow generalization because it leaves unmarried or differently-married women [5]. Binarization of the variable of interest in the decision-making process might reduce the complexity of SRH autonomy thus leaving aside the subtle differences.

5. CONCLUSION

This research capitalised on the potential of machine learning to foresee sexual and reproductive health (SRH) decision making autonomy by women in Nigeria based on the extensive data of the 2023-2024 Nigeria Demographic and Health Survey (NDHS). The XGBoost model, consisting of an 81.8 accuracy rate on the test sample and 100-perfect precision in predicting the autonomy of high autonomy women, highlighted the potential of the use of artificial intelligence in the design of health initiatives aimed at women, echoing the worldwide commitment to pitching women into the next level of their health by using data-driven methods [20]. The use of contraceptives became central to autonomy, and traditional approaches, such as withdrawal or periodic abstinence were found to collect the most predictive weight (importance: 0.3511), based on the cultural practices that may be longstanding and all-encompassing in influencing decisions about reproduction [13],[14]. The spatial analysis showed that not only was the North-South gradient pronounced, but that the northern states, such as the North-East and the North-West, did not reveal any expected high autonomy as the South-South did with 80 percent [4]. Such differences, reflecting those observed in NDHS, with 6.7 percent autonomy in North-West and 72.7 percent in South-South, demonstrated systemic issues, including low level of education and poverty in the North [6]. The results obtained supported the idea of culturally-sensitive health initiatives, where the focus was on the availability of various contraceptives, with a special emphasis on traditional options, in order to increase autonomy, especially in poor regions. For future studies, researchers should consider studying more diverse and extensive data sets, combine qualitative data on the role of culture and religious affiliation, and formulate health-related metrics to achieve a better predictive accuracy.

6. ACKNOWLEDGMENTS

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