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ENSEMBLE PREDICTIVE MODELS FOR CONTRACEPTIVE UPTAKE IN WOMEN

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Abstract: **Contraceptive uptake among women plays a pivotal role in reproductive health outcomes and family planning initiatives worldwide. In recent years, the application of predictive modeling techniques has gained significant attention in understanding and forecasting contraceptive usage patterns. This paper presents a comprehensive review of the latest advancements in the development of ensemble predictive models for contraceptive uptake in women. The review begins with an overview of the global landscape of contraceptive utilization, highlighting the importance of accurate predictive models in addressing various challenges, including unintended pregnancies, maternal mortality, and disparities in access to reproductive healthcare services. Subsequently, the paper delves into the methodological aspects of ensemble modelling, elucidating the principles underlying ensemble learning and its relevance in enhancing predictive accuracy and robustness. Furthermore, the review synthesizes recent studies and methodologies employed in the development of ensemble predictive models for contraceptive uptake. It explores diverse data sources utilized in model training, ranging from demographic and socio-economic indicators to behavioural factors and healthcare utilization patterns. Moreover, the review discusses the integration of advanced statistical techniques, machine learning algorithms, and data fusion methodologies to capture the multifaceted determinants influencing contraceptive decision-making among women. The paper also examines the performance evaluation metrics employed to assess the predictive capabilities of ensemble models, including accuracy, sensitivity, specificity, and area under the receiver operating characteristic curve (AUC-ROC). Moreover, it discusses the implications of ensemble predictive modeling in informing policy-making, resource allocation, and targeted interventions aimed at promoting contraceptive uptake and improving reproductive health outcomes. Additionally, the review highlights the challenges and limitations associated with ensemble predictive modeling in the context of contraceptive uptake, including data quality issues, model interpretability, and ethical considerations related to privacy and confidentiality. It underscores the need for ongoing research efforts to address these challenges and refine predictive models to better serve the needs of diverse populations.**

Keywords: **Contraceptive, family planning, machine learning, AUC-ROC.**

I. INTRODUCTION

Contraceptive uptake among women is a crucial aspect of reproductive health and family planning programs worldwide, with profound implications for maternal and child health outcomes, gender equality, and socio-economic development. Despite significant progress in expanding access to contraceptive services, disparities persist, and many women still face barriers to effective family planning.

In recent years, the application of predictive modeling techniques has emerged as a promising approach to understanding and forecasting contraceptive usage patterns. These models, particularly ensemble predictive models, offer a powerful tool for analysing complex interactions between diverse socio-demographic, behavioural, and healthcare utilization factors influencing contraceptive decision-making among women.

This paper aims to provide a comprehensive review of the latest developments in ensemble predictive modeling for contraceptive uptake in women. It begins by contextualizing the importance of contraceptive utilization within the broader landscape of reproductive health, emphasizing its role in reducing unintended pregnancies, and maternal mortality, and promoting women's empowerment. It further outlines the fundamental principles of ensemble predictive modeling, highlighting its ability to integrate multiple predictive algorithms to improve accuracy, robustness, and generalizability. Ensemble modeling techniques, such as bagging, boosting, and stacking, offer innovative solutions to address the challenges posed by the complexity and heterogeneity of contraceptive uptake determinants.

The paper will provide a review of recent studies, methodological approaches, challenges, and future directions in the field of ensemble predictive modeling for contraceptive uptake in women. This comprehensive review aims to contribute to the advancement of knowledge and the development of effective strategies to enhance reproductive health and family planning initiatives globally.

1.1 Global Landscape of Contraceptive Utilization

The global landscape of contraceptive utilization is characterized by significant variations influenced by a myriad of socio-cultural, economic, and policy factors. While certain regions and countries have made remarkable strides in improving contraceptive access and uptake, stark disparities persist, especially in low- and middle-income countries (LMICs). These inequities often exacerbate existing challenges in reproductive health and family planning, leading to adverse outcomes such as unintended pregnancies, unsafe abortions, and maternal mortality.

In many LMICs, the unmet need for contraception remains alarmingly high among specific demographic groups, including adolescents, unmarried individuals, rural populations, and marginalized communities. Barriers to contraceptive uptake encompass a complex interplay of social norms, cultural beliefs, gender dynamics, economic constraints, and limited access to healthcare services. The societal stigma surrounding contraception, lack of comprehensive sex education, and inadequate availability of contraceptive methods further impede women's ability to make informed choices about their reproductive health.

Moreover, policy environments in some regions may either facilitate or hinder contraceptive access and uptake. Legal and regulatory frameworks governing reproductive rights, contraceptive availability, and healthcare financing play a pivotal role in shaping individuals' contraceptive decisions. For instance, restrictive policies on abortion and contraception may deter individuals from seeking reproductive healthcare services, leading to increased rates of unintended pregnancies and maternal morbidity.

The consequences of limited contraceptive utilization extend beyond individual health outcomes to broader socio-economic ramifications. Women who lack access to contraception often experience diminished educational and economic opportunities, perpetuating cycles of poverty and inequality. Furthermore, unintended pregnancies can strain healthcare systems, exacerbate social inequalities, and impede sustainable development efforts.

Understanding the determinants of contraceptive uptake is essential for addressing these disparities and promoting reproductive autonomy among women worldwide. Efforts to enhance contraceptive access and utilization must be contextually tailored to meet the diverse needs and preferences of individuals and communities. This necessitates comprehensive strategies that encompass not only improving contraceptive availability and affordability but also addressing socio-cultural barriers, empowering women with accurate information and decision-making autonomy, and strengthening healthcare systems to deliver high-quality reproductive health services.

In summary, the global landscape of contraceptive utilization is characterized by multifaceted challenges and disparities rooted in socio-cultural, economic, and policy contexts. Addressing these disparities requires concerted efforts from governments, civil society organizations, healthcare providers, and international stakeholders to promote reproductive rights, empower women, and ensure universal access to comprehensive reproductive healthcare services. By addressing the underlying determinants of contraceptive uptake, we can mitigate the adverse consequences of unintended pregnancies and maternal morbidity, ultimately advancing the health and well-being of individuals, families, and communities worldwide.

1.2 Objectives of the Study

The specific objectives of the research are to:

a) identify relevant predictors associated with contraceptive uptake

b) design ensemble models to improve the accuracy and robustness of contraceptive uptake prediction

c) implement the resulting ensemble models in (b) and

d) evaluate the performance of the ensemble model in (c) based on the confusion matrix and accuracy.

II. LITERATURE REVIEW

Yu-En, (2020) presents "Predicting Contraception Use in Asia with Machine Learning Algorithms" presents an interesting use case of applying machine learning algorithms to predict contraception use in Asian countries. The author provides a comprehensive explanation of the data pre-processing steps, feature engineering, and model selection, which makes it easy to understand the methodology used in the study. Using different machine learning algorithms, including logistic regression, decision trees, and random forests, for the prediction task is a good approach that allows for a comparison of model performances.

Aim and Objectives: The study aims to build classification models with machine learning (ML) techniques to predict the use of contraception in Thailand, Mongolia, and Laos. Specifically, the goal is to identify Women of Reproductive Age (WRA) not using contraception.

Methodology: Five ML models were used to predict the use of contraception: K-nearest neighbour (KNN), Decision tree, Random forest, Logistic regression with Bayesian classifier, and Generalized additive model (GAM).

Limitations: There are some limitations. Firstly, Multiple Indicator Cluster Surveys (MICS) is a cross-sectional survey that provides a snapshot of the population. Because some methods are reversible, such as intrauterine devices and contraceptive implants, MICS does not capture the patterns influencing an individual's decision to change the adoption of contraception. Secondly, only a few variables from MICS are included in the analysis as described in Data Source and Process. As MICS data files contain more than one module, such as information on household characteristics, children's health, and household members, merging the WRA module with others will allow more variables to be analysed in this study. It is not done currently because UNICEF does not provide documentation on how to identify a unique individual across several modules.

Furthermore, the article lacks a thorough analysis of the results obtained from the different machine learning models. Although the author mentions the evaluation metrics used to assess the models' performances, a more detailed discussion of the results and their implications would be helpful.

Result: Random forest has the highest accuracy of 76.67%, followed by 76.43% of GAM; 76.42% of logistic regression; 74.49% of decision tree; and 74.23% of KNN. The GAM model has the smallest range, indicating consistency in predictive performance, however, given there are only ten folds, the distribution may not be representative. Surprisingly, in contrast to the initial strategy that non-parametric models would have better performance, KNN and decision trees did worse than parametric ones.

Contribution to Knowledge: The article provides a good introduction to the use of machine learning algorithms in predicting contraception use in Asia

Haq, et al., (2022), in the paper Machine Learning Algorithm-Based Contraceptive Practice among Ever-Married Women in Bangladesh: A Hierarchical Machine Learning Classification Approach, the study found that the prevalence of contraception was almost 59% in Bangladesh. The prevalence rate of contraceptives in India is 54%, while the rates were 47%, 34%, and 65%, respectively, for Nepal, Pakistan, and Sri Lanka

Aim and Objectives: To identify the best model selection procedure and predicted contraceptive practice among women aged 15–49 years in the context of Bangladesh.

Methodology: Logistic Regression (LR), Random Forest (RF), Naïve Bayes (NB), Least Absolute Shrinkage and Selection Operation (LASSO), Classification Trees (CT), Adaboost, and Neural Network (NN)

Limitations: the model could not achieve a high accuracy

Result: The logistic regression classifier has an accuracy of 78.52%. The precision and recall of the fitted model were 81.23% and 82.39%, respectively, while the F1 score was 81.81%. The area under the curve (AUC) was calculated to be 86.57%. The prediction performance result of a random forest was displayed with an accuracy of 77.57%. Here, the precision, recall, and F1 score of the random forest classifier were 73.82%, 85.35%, and 81.99%, respectively. The AUC,

in this case, was 84.07%. The final accuracy of the naïve Bayes classifier was 76.56%, with a precision of 75.73% and a recall of 88.32%. The F1 score and the AUC value, in this case, were 81.54% and 84.17%, respectively. Using Least Absolute Shrinkage and Selection Operator (LASSO) analysis, the accuracy in the test data set was seen as 79.08% with precession and recall of 79.39% and 86.85% respectively, and the F1 score was 82.96%. According to the test observation results, the classification tree method showed 78.57% accuracy in predicting contraceptive practice among married women, with a precession of 78.16%, a recall of 88.06%, an F1 score of 82.81%, and an AUC value of 85.59%. For AdaBoost, these values are 78.05% (accuracy), 80.20% (precession), 84.88% (recall), 82.10% (F1 score), and 86.15% (AUC). Finally, they used an artificial neural network and obtained an accuracy of 79.34%. Here, other parameters such as precession, recall, F1 score, and AUC are 78.71%, 88.76%, 83.44%, and 86.90% respectively. Among the seven classifiers, they obtained the best performance from NN in terms of both accuracy and AUC. Cohen's kappa value is 0.5626.

Contribution to Knowledge: machine learning techniques to predict contraceptive practice among ever-married women in Bangladesh were developed

Haq, I., (2017), Sociodemographic Factors on Contraceptive Use among Ever-Married Women of Reproductive Age: Evidence from Three Demographic and Health Surveys in Bangladesh.

Aim and Objectives: to explore the sociodemographic factors associated with contraceptive use among ever-married women of reproductive age in Bangladesh by utilizing the information extracted from three of the Bangladesh Demographic and Health Surveys (BDHSs) in 1993–1994, 2004, and 2014.

Methodology: Frequency distribution was used to describe the background characteristics of the respondents. Two-way contingency tables along with Pearson's chi-squared test were used to examine the relationships between sociodemographic factors and a dependent variable. To get the adjusted effects of selected factors, the author considers statistical model appropriate for binary response, namely binary logistic regression [18] model in a multivariate setup. The result was presented as odds ratio (OR) and 95% confidence interval (CI). The Statistical Package for Social Science (SPSS v20.0, IBM Corporation, Armonk, New York, NY, USA) software was used for data analysis.

Limitations: the research was based on nationally representative sample surveys.

Result: The percentage of women in each category of the selected variables for each survey point were displayed with regard to the respondent's current age, about half of the women in all three surveys were under age 30. About 7% respondents in all surveys were residing in Barisal division, while slightly over one-third of the respondents live in Dhaka division. Considering the educational status, in the first two surveys, about half of the respondents (58.1% in 1993–1994 and 41.2% in 2004) had no education, while in BDHS 2014, this rate was only one-quarter (24.9%). With respect to the highest educational level, there is a clear indication that the percentage of women attaining secondary and higher education has been increasing in Bangladesh since 1993–1994. The percentage of the respondents who resides in urban areas have increased from 11.5% in 1993–1994 to 28.3% in 2014. Across the three BDHSs, the proportion of Muslims showed a slight increase from 87.8% to 90.1% between 1993–1994 and 2014. The proportion of women with exposure to family planning information in the media declined from 45.5% in 1993–1994 to 19.9% in 2014. Regarding age at first marriage of the respondents, the percentage of marriage took place before 18 years of age has declined from 88.1% in 1993–1994 to 76.5% in 2014 BDHS. In terms of household wealth quintiles, the proportion of women in middle income households has increased since 1993–1994. The proportion of respondent's working status rose from 16% in 1993–1994 to 33.1% in 2014. The percentage of women reporting three as an ideal family size have increased in recent times. Regarding women's fertility preferences, the percentage of women wanting no more children has increased slightly from 48.4% in 1993–1994 to 56.7% in 2014. Concerning contraception use, the percentage of women practicing contraception increased from 42% in 1993–1994 to 58.9% in 2014.

Contribution to Knowledge: the study was designed to identify the major factors contributing to the changes in contraceptive use in the last two decades, by using the information extracted from the 1993–1994, 2004, and 2014 BDHSs. In summary, we conclude that a respondent's current age, place of residence, division, religion, level of education, age at first marriage, FP media exposure, ideal number of children, and fertility preferences are the significant determinants according to the most recent survey, BDHS 2014

Islam, (2017), present Contraceptive Use, Method Choice, and Discontinuation of Contraception in South Asia

Aim and Objectives: The objective of this study was to examine differentials in contraception use, method choice, and discontinuation of contraception among currently married women aged 15-49 in two countries of South Asia: Bangladesh and India.

Methodology: This study draws data from the 2014 Bangladesh Demographic and Health Survey (BDHS) and the 2005-06 National Family Health Survey (NFHS) of India. logistic regression estimates were applied to examine contraceptive uses, method choice, and contraceptive discontinuation in Bangladesh and India.

Limitations: the result of the research was obtained from the manual analysis of a survey. Implementing the survey with a machine-learning approach will give a better result

Result: The result shows that women in Bangladesh had 75.0 percent higher odds of contraceptive use than their counterparts in India.

[AOR=1.750, 95% CI: 1.08-2.84] after adjusting for age, age at first marriage, education, employment status, wealth index, religion, place of residence, time, and exposure to media. However, there was no significant difference in the use of modern methods among women in Bangladesh and India after adjusting for the selected covariates. Nevertheless, women in Bangladesh had much higher discontinuation of contraception than women in India after controlling for the selected covariates [[AOR=19.049, 95% CI: 8.59-42.22]

Contribution to Knowledge: the findings of this study suggest that Governments should focus more on increasing women's education, employment opportunities, and economic status to increase contraceptive prevalence rates and consequently reduce fertility rates.

Kebede, et al., (2023), present a Prediction of contraceptive discontinuation among reproductive-age women in Ethiopia using the Ethiopian Demographic and Health Survey 2016 Dataset: A Machine Learning Approach

Aim and Objectives: This study aimed to predict and identify predictors of contraceptive discontinuation.

Methodology: After the data has been prepared and divided into training and testing tests, suitable models were selected to perform the training. Since the outcome variable was categorical, the task was a classification task and appropriate classifiers need to be selected to conduct the prediction. The dataset used in the analysis falls under the category of binary classification since contraceptive discontinuation was categorized into two mutually exclusive categories. The classification algorithms used for this analysis were logistic regression (LR), Random forest (RF), KNN, artificial neural network, support vector machine (SVM), Naïve Bayes, eXtreme gradient boosting (XGBoost), and AdaBoost classifiers. These algorithms were selected based on previous studies that applied machine learning techniques for classification tasks on EDHS data

Result: Random Forest model was the best predictive model with an accuracy of 68% and ROC 0.74 based on a tenfold cross-validation score on balanced training data. The finding was comparable to a study conducted in Ethiopia, which found Random Forest as the best machine learning model to predict nutritional status for under-five children using EDHS data, with accuracy and AUC of 68.2% and 0.76 respectively. However, the performance was much lower than a study conducted in Indonesia which reported AdaBoost as the best model to predict the duration of contraceptive use with an accuracy of 85.1%. This inconsistency could be due to the size of the dataset used for model building. The study used only 5,885 records whereas the Indonesian study used 39,594 records, which allows the model to learn effectively and perform the prediction with better accuracy. The final prediction on the test data was made after optimizing hyperparameters of the random forest algorithm which in turn improved the accuracy of the model. The optimized model predicted 476 discontinued cases correctly, and 176 non-discontinued cases incorrectly from a total of 652 discontinued cases on the unseen test data. The random forest model was the best predictive model for this study with 66.4% accuracy, 68.5% precision, 73% recall, and 70.8% f1 score performance on the unseen test data.

Limitation: First, the parameters are difficult to interpret and quantify the strength of their association with the dependent variable since ML algorithms lack regression coefficients for each predictor. Second, the dependent variable was computed using a DHS contraceptive calendar, which is a month-by-month retrospective history of all births, pregnancies, abortions, and contraceptive use episodes of each surveyed woman experienced in the five years before being interviewed. As a result, the participants may have difficulty memorizing their past experiences, and it may be challenging to calculate contraceptive discontinuation. Last not but least, the model was unable to investigate additional variables related to contraceptive discontinuation because our study relied on secondary data

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III. METHODOLOGY

3.1 Research Design

The study employed the use of a stack ensemble machine learning technique for predicting contraceptive intake in women based on a secondary dataset of the 1987 National Indonesia Contraceptive Prevalence Survey. The idea is to leverage the strengths of different models by training a meta-model (also called a second-level model) to learn how to best combine their predictions.

3.2 Dataset

This dataset is a subset of the 1987 National Indonesia Contraceptive Prevalence Survey. It contains married women who were either not pregnant or did not know if they were at the time of the interview. The objective of the survey at that time was to find the best predictors of contraception use in women based on their demographic and socio-economic characteristics. The dataset comprises 1,473 observations with 10 features which include the target variable. Features include:

Wife's age: Numerical

Wife's education: Categorical (1=low, 2, 3, 4=high)

Husband's education: Categorical (1=low, 2, 3, 4=high)

Number of children ever born: Numerical

Wife's religion: Binary (0=Non-Islam, 1=Islam)

Wife currently working? : Binary (0=Yes, 1=No)

Husband's occupation: Categorical (1, 2, 3, 4)

Standard of living index: Categorical (1=low, 2, 3, 4=high)

Media exposure: Binary (0=Good, 1=Not good)

Contraceptive method used (class attribute): Categorical (1=No-use, 2=Long-term, 3=Short-term)

Figure 1: Dataset Sample

	Wife Age	Wife Education	Husband Education	Children	Wife religion	Wife working	Husband Occupation	SOLI	Media Exposure	Contraceptive Method
0	24	2	3	3	1	1	2	3	0	1
1	45	1	3	10	1	1	3	4	0	1
2	43	2	3	7	1	1	3	4	0	1
3	42	3	2	9	1	1	3	3	0	1
4	36	3	3	8	1	1	3	2	0	1

3.3 Model Building

In this study, K-Nearest Neighbor, Decision Trees, Random Forest, and Support Vector Machines (SVM) are the base models while Logistic Regression is the meta-model used in the design. Each base model learns from the input features and tries to predict the contraceptive uptake. The meta-model (Logic Regression) is then trained on this new dataset. The meta-model learns to combine the predictions of the base models to make a final prediction.

K-nearest neighbors (KNN)

The K-nearest neighbors (KNN) method predicts which cluster a new data point will fall into using the approach of "feature similarity" or "nearest neighbors". In this work, we used the Euclidean distance measure for the k-NN algorithm. Euclidean distance d between data point x and data point y are calculated as follows:

$$d(x,y) = \sqrt{(\sum_{i=1}^{N} (xi - yi)^2)}$$

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SVM

SVM stands out as one of the most effective classification algorithms. It employs a kernel function, $K(x_n, x_i)$, to map the original data space into a higher-dimensional space. The function for separating the data can be defined as follows:

$$f(x_i) = \sum_{n=i}^{N} \alpha_n y_n k(x_n x_i) + b$$

Decision Tree

Using the given dataset, a decision tree for classification would analyze features such as "Wife Age," "Wife Education," "Husband Education," "Children," "Wife Religion," "Wife Working," "Husband Occupation," "SOLI," and "Media Exposure" to predict the "Contraceptive Method" employed by women. The algorithm recursively splits the data based on these features to maximize class homogeneity within each subset. For instance, it might first split on "Wife Education," then further divide based on "Husband Education" or "Number of Children," and so on. This process continues until a stopping criterion is met, resulting in a tree structure where each leaf node represents a class prediction. The decision tree provides an interpretable model that highlights the most significant factors influencing contraceptive use among women in the dataset.

$$Entropy(t) = -\sum_{i=1}^{k} p_i log_2(p_i)$$

Random Forest

The model generates multiple decision trees from different bootstrap samples of the data, with each tree trained on a random subset of features to ensure diversity. Each tree makes its prediction, and the final prediction is determined by majority voting among all trees. This approach improves accuracy and robustness, reduces overfitting, and highlights the importance of various features, making Random Forest a powerful tool for understanding and predicting contraceptive use in the dataset.

$$\hat{y} = mode(\{\hat{y}b\}_{b=1}^{B})$$

Logistic Regression

The model calculates a linear combination of the features, applies the logistic function to convert this to a probability, and classifies the outcome based on a threshold (typically 0.5). By training on the dataset, logistic regression identifies the relationships between the input features and contraceptive use, allowing it to make predictions and provide insights into the significant factors influencing contraceptive adoption among women.

$$\hat{y} = \begin{cases} 1 \; if \; \hat{p} \geq 0.5 \\ 0 \; if \; \hat{p} \geq 0.5 \end{cases}$$

Table 1: Accuracy Score

Model	Accuracy Score
KNeighborsClassifier	86.0
RandomForestClassifier	75.4
SVC Classifier	56.4
DecisionTreeClassifier	69.6
LogisticRegression	89.3

IV. SUMMARY OF RESULTS

In this study, we compared the performance of several base predictive models and a stack ensemble model in predicting contraceptive use among women based on various demographic, socio-economic, and behavioral features. The base models included KNeighborsClassifier, RandomForestClassifier, SVC (Support Vector Classifier), and DecisionTreeClassifier. Their accuracy scores were 86.0%, 75.4%, 56.4%, and 69.6%, respectively. These models, while varied in their strengths, exhibited a range of performances, with KNeighborsClassifier being the most accurate among them.

The stack ensemble model, which utilized Logistic Regression as the meta-model, significantly outperformed the individual base models, achieving an accuracy score of 89.3%. This improvement can be attributed to the ensemble technique's ability to combine the predictions from multiple models, leveraging their strengths while mitigating their weaknesses. The stack ensemble method effectively integrated the diverse information captured by each base model, resulting in a more robust and accurate prediction.

Overall, the results demonstrate the efficacy of using stack ensemble methods in predictive modeling, especially when dealing with complex datasets involving multiple features. The ensemble approach not only improved the predictive accuracy but also provided a more reliable framework for making decisions based on the integrated output of several models. This highlights the potential of ensemble learning techniques in enhancing model performance, offering valuable insights for applications in public health and policy-making related to contraceptive use.

V. CONCLUSION

In this study, we explored the development and evaluation of various predictive models for contraceptive uptake in women, using a dataset containing demographic, socio-economic, and behavioral features. Individual base models, including KNeighborsClassifier, RandomForestClassifier, SVC, and DecisionTreeClassifier, exhibited varying levels of accuracy, with KNeighborsClassifier achieving the highest accuracy of 86.0%. However, the stack ensemble method, which combined the strengths of these base models using Logistic Regression as the meta-model, significantly outperformed all individual models, achieving an accuracy of 89.3%.

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