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TabNet Prediction of Depression Risk Among Women Through Rumination, Social Isolation, Self-Criticism, and Intolerance of Uncertainty

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A B S T R A C T

Objective: The present study aimed to predict depression risk among women using rumination, social isolation, self-criticism, and intolerance of uncertainty through an explainable TabNet machine learning model and to determine the relative importance of these predictors in identifying individuals at elevated risk for depressive symptoms.

Methods and Materials: This cross-sectional predictive study was conducted among 1,248 women residing in Kenya. Participants were recruited using a stratified convenience sampling strategy from community health centers, educational institutions, workplaces, and online platforms. Data were collected using standardized self-report measures, including the Patient Health Questionnaire-9 (PHQ-9) for depression risk, the Ruminative Responses Scale (RRS), the Lubben Social Network Scale-Revised (LSNS-6), the Levels of Self-Criticism Scale (LOSC), and the Intolerance of Uncertainty Scale-12 (IUS-12). Following data preprocessing and standardization, the dataset was divided into training (70%), validation (15%), and testing (15%) subsets. A TabNet deep learning model was developed and optimized using cross-validation and hyperparameter tuning procedures. Model performance was evaluated using the coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and mean squared error (MSE). Feature importance and SHAP analyses were conducted to enhance interpretability.

Findings: The TabNet model demonstrated excellent predictive performance, achieving an R^2 of .874 in the training set, .846 in the validation set, and .832 in the testing set. Correlation analyses indicated significant positive associations between depression risk and rumination (r = .71), self-criticism (r = .68), intolerance of uncertainty (r = .65), and social isolation (r = .63). Feature importance analysis revealed that rumination was the strongest predictor (33.8%), followed by self-criticism (27.9%), intolerance of uncertainty (22.1%), and social isolation (16.2%). SHAP analysis confirmed that higher levels of all four predictors contributed to

increased depression risk. Classification analyses further demonstrated strong model accuracy, yielding an overall F1-score of .86 and particularly high performance in identifying severe depression risk cases.

Conclusion: The findings indicate that depression risk among women can be accurately predicted using a combination of cognitive and social vulnerability factors. Rumination emerged as the most influential predictor, highlighting the central role of repetitive negative thinking in depressive symptomatology. The results support transdiagnostic models of emotional disorders and demonstrate the utility of explainable machine learning approaches for mental health screening, early detection, and personalized intervention planning.

Keywords: *Depression Risk; Women; TabNet; Machine Learning; Rumination; Self-Criticism; Social Isolation; Intolerance of Uncertainty.*

1. Introduction

Depression is among the most prevalent and disabling mental health conditions worldwide and constitutes a major public health concern for women across diverse sociocultural contexts. Women consistently report higher rates of depressive symptoms and depressive disorders than men, a disparity attributed to a complex interaction of biological, psychological, interpersonal, and environmental factors. Depression in women is associated with substantial impairments in emotional functioning, interpersonal relationships, occupational productivity, physical health, and overall quality of life. Furthermore, depressive symptoms frequently co-occur with anxiety, stress-related conditions, and maladaptive cognitive patterns, creating a cycle of psychological vulnerability that may persist over time if left untreated. Recent developments in mental health research have increasingly emphasized the importance of identifying modifiable cognitive and social risk factors that contribute to depression, particularly among women who may experience unique stressors related to caregiving responsibilities, social expectations, economic pressures, and interpersonal relationships (Hernández-Posadas et al., 2023; Katzman et al., 2023; Monferrer et al., 2023).

The emergence of transdiagnostic approaches has significantly advanced understanding of depression by highlighting common psychological processes that underlie multiple forms of emotional distress. Rather than focusing exclusively on disorder-specific symptoms, transdiagnostic frameworks seek to identify broad mechanisms that contribute to a range of psychological difficulties. Depression has been increasingly conceptualized as the outcome of interacting cognitive, emotional, and social vulnerabilities that transcend traditional diagnostic categories. Systematic reviews have demonstrated that factors such as repetitive negative thinking, intolerance of uncertainty, social disconnection, emotional avoidance, and maladaptive self-evaluation are consistently associated with depressive symptomatology across different populations and clinical conditions (Flynt et al., 2025; Hernández-Posadas et al., 2023; Moreno-Mansilla et al., 2021). Consequently, understanding how these transdiagnostic vulnerabilities interact to predict depression risk among women represents an important direction for contemporary psychological research.

Among the most extensively studied cognitive risk factors for depression is rumination. Rumination refers to a repetitive and passive focus on negative emotions, perceived failures, personal shortcomings, and distressing experiences. Rather than facilitating problem solving, ruminative thinking tends to maintain and intensify negative affect by repeatedly directing attention toward sources of distress. Individuals who engage in chronic rumination often experience difficulties disengaging from negative thoughts, leading to heightened emotional suffering and increased susceptibility to depressive episodes. Research has consistently identified rumination as a significant predictor of depression severity, psychological distress, and emotional dysfunction. During periods of uncertainty and stress, ruminative thinking appears to amplify perceptions of threat and helplessness, thereby increasing vulnerability to depression and anxiety-related outcomes (Torrente et al., 2021; Yiğitoğlu et al., 2023; Zhang et al., 2023). Furthermore, studies examining pandemic-related psychological challenges have found that rumination serves as a central mechanism linking stress exposure to emotional distress, suggesting that repetitive negative thinking may constitute a particularly important risk factor for women's mental health (Harrison et al., 2022; Songco et al., 2023).

Another critical factor associated with depression is social isolation. Human beings possess an inherent need for social connection, emotional support, and meaningful

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interpersonal relationships. When these needs remain unmet, individuals may experience loneliness, alienation, and reduced psychological well-being. Social isolation has been repeatedly linked to elevated levels of depression, anxiety, stress, and reduced life satisfaction. Research conducted during periods of widespread social disruption has demonstrated that reduced social interaction significantly increases vulnerability to emotional disorders. Individuals experiencing greater social isolation often report lower levels of resilience and fewer resources for coping with adversity, making them more susceptible to depressive symptoms (Muls et al., 2022; Phillips et al., 2023; Zsidó et al., 2022). Moreover, perceived social support appears to buffer the negative effects of psychological stress, whereas loneliness and social withdrawal contribute substantially to emotional distress. Evidence indicates that repetitive negative thinking may partially explain the relationship between inadequate social support and depression, highlighting the interconnected nature of social and cognitive vulnerabilities (Harrison et al., 2022; Zhuo et al., 2021).

Self-criticism represents another prominent psychological characteristic associated with depression. Self-critical individuals tend to evaluate themselves harshly, focus excessively on personal shortcomings, and engage in persistent self-blame. These cognitive tendencies can undermine self-esteem, reduce perceived competence, and intensify negative emotional experiences. Self-criticism has been identified as a major contributor to depression because it promotes maladaptive interpretations of stressful events and reinforces feelings of worthlessness and hopelessness. Women may be particularly vulnerable to self-critical thinking due to societal pressures regarding appearance, achievement, caregiving responsibilities, and interpersonal success. Research examining emotional distress has consistently found that negative self-evaluation contributes to both the onset and maintenance of depressive symptoms. Interventions targeting self-compassion and adaptive emotional regulation have demonstrated protective effects against depression, suggesting that self-critical cognitions represent a modifiable psychological risk factor (Cutajar & Bates, 2025; Flynt et al., 2025; Katzman et al., 2023).

Intolerance of uncertainty has emerged as one of the most influential transdiagnostic constructs in contemporary psychological science. Defined as a dispositional tendency to perceive uncertain situations as threatening, intolerance of uncertainty influences how individuals interpret ambiguity, anticipate future events, and respond to perceived unpredictability. Individuals characterized by high intolerance of uncertainty frequently experience elevated worry, anxiety, emotional distress, and cognitive rigidity. Although initially examined primarily within anxiety disorders, recent research has demonstrated that intolerance of uncertainty is strongly associated with depressive symptoms and broader psychological dysfunction. The inability to tolerate ambiguity may promote feelings of helplessness, hopelessness, and emotional exhaustion, thereby increasing vulnerability to depression (Gosselin et al., 2022; İnözü et al., 2022; Nekić, 2023).

A growing body of evidence suggests that intolerance of uncertainty may exert its influence on depression through multiple cognitive and emotional pathways. For example, intolerance of uncertainty has been linked to maladaptive emotion regulation strategies, psychache, loneliness, worry, and repetitive negative thinking. Individuals who struggle with uncertainty often engage in rumination as an attempt to gain cognitive control over ambiguous situations; however, such efforts frequently intensify emotional distress rather than alleviate it. Recent studies have demonstrated that intolerance of uncertainty predicts depression severity and diagnostic status even after controlling for other psychological variables. Furthermore, intolerance of uncertainty has been identified as a mediator linking perceptions of unsafety and environmental stressors to depressive symptoms and diminished well-being (Assaf et al., 2025; Choudhary et al., 2023; Wu et al., 2025). Similar findings have emerged across diverse cultural contexts, highlighting the broad relevance of uncertainty-related vulnerabilities in psychological functioning (Kesner et al., 2025; Kim et al., 2025).

The relationships among rumination, social isolation, self-criticism, and intolerance of uncertainty appear to be particularly important for understanding depression risk. Individuals who are unable to tolerate uncertainty often engage in repetitive negative thinking, which may subsequently increase emotional distress and depressive symptoms. Likewise, socially isolated individuals may have fewer opportunities to challenge negative cognitions through interpersonal feedback, thereby increasing the likelihood of rumination and self-critical thinking. These factors may interact synergistically rather than independently, creating a constellation of vulnerabilities that substantially elevate depression risk. Research examining transdiagnostic mechanisms has increasingly emphasized the need to investigate multiple risk factors simultaneously in order to capture the complexity of psychological disorders (Flynt et

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al., 2025; Gerdan & Şalcıoğlu, 2025; Hernández-Posadas et al., 2023).

Although substantial evidence supports the importance of these variables, most previous investigations have relied on conventional statistical approaches such as correlation analysis, multiple regression, and structural equation modeling. While these methods provide valuable insights into linear relationships among variables, they may be less effective in capturing complex nonlinear interactions that characterize psychological phenomena. Mental health outcomes frequently arise from dynamic combinations of cognitive, emotional, and social factors whose relationships may vary across individuals and contexts. Consequently, there is increasing interest in applying machine learning techniques to psychological research in order to enhance predictive accuracy and identify patterns that may not be detectable through traditional analytic methods.

Among contemporary machine learning approaches, TabNet represents a particularly promising methodology for psychological prediction. Unlike many traditional machine learning algorithms that function as “black boxes,” TabNet employs sequential attention mechanisms that enable both high predictive performance and interpretability. The model can identify the relative importance of predictor variables while simultaneously capturing nonlinear relationships and complex interactions among features. Such capabilities make TabNet especially suitable for investigating depression risk, where multiple psychological factors are likely to contribute differentially to individual outcomes. The integration of machine learning methods into mental health research aligns with broader efforts to improve early identification, prevention, and intervention strategies for individuals at risk of psychological disorders.

Despite growing recognition of the roles of rumination, social isolation, self-criticism, and intolerance of uncertainty in depression, several important gaps remain in the literature. First, relatively few studies have examined these variables simultaneously within a unified predictive framework. Second, limited research has focused specifically on women, despite evidence suggesting that women may experience heightened vulnerability to both depression and many of its underlying cognitive risk factors. Third, investigations utilizing advanced explainable machine learning approaches remain scarce, particularly in African contexts where mental health research is comparatively underrepresented. Addressing these gaps may contribute to a more comprehensive understanding of depression risk and facilitate the development of targeted prevention strategies.

Therefore, the aim of the present study was to predict depression risk among women using rumination, social isolation, self-criticism, and intolerance of uncertainty through the application of an explainable TabNet machine learning model.

2. Methods and Materials

2.1. Study design and Participant

This study employed a cross-sectional predictive research design to investigate the extent to which rumination, social isolation, self-criticism, and intolerance of uncertainty could predict depression risk among women using the TabNet deep learning framework. The study was conducted in Kenya between January and June 2026. The target population consisted of adult women residing in both urban and rural regions of the country. A total of 1,248 women participated in the study. Participants were recruited through community health centers, women's organizations, universities, workplaces, and online social networks using a stratified convenience sampling approach to ensure representation across different age groups, educational levels, and socioeconomic backgrounds.

Eligibility criteria included being female, aged 18 years or older, residing in Kenya for at least one year, and having sufficient literacy to complete the study questionnaires in English or Swahili. Individuals with severe cognitive impairment or those who reported current psychiatric hospitalization were excluded from participation. Prior to data collection, all participants received information regarding the purpose of the study and provided informed consent electronically or in written form. Participation was voluntary, anonymity was guaranteed, and participants were informed of their right to withdraw from the study at any stage without penalty.

2.2. Measures

Depression risk was assessed using the Patient Health Questionnaire-9 (PHQ-9), developed by Kroenke, Spitzer, and Williams in 2001. The PHQ-9 is one of the most widely used self-report instruments for screening depressive symptoms and consists of nine items corresponding to the diagnostic criteria for major depressive disorder. Participants rate the frequency of symptoms experienced during the previous two weeks using a four-point Likert scale ranging from 0 (not at all) to 3 (nearly every day). Total scores range from 0 to 27, with higher scores indicating

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greater depression severity and elevated risk of depressive disorders. Previous studies conducted across diverse populations have demonstrated strong psychometric properties, including satisfactory internal consistency, construct validity, criterion validity, and test-retest reliability.

Rumination was measured using the Ruminative Responses Scale (RRS), developed by Nolen-Hoeksema and Morrow in 1991 and later refined by Treynor and colleagues. The scale evaluates individuals' tendency to repetitively focus on negative emotions, distress, and their possible causes and consequences. The instrument contains 22 items rated on a four-point Likert scale ranging from 1 (almost never) to 4 (almost always). The scale assesses dimensions such as brooding and reflective pondering. Higher scores indicate greater engagement in ruminative thinking patterns. Extensive research has supported the reliability and validity of the RRS in both clinical and non-clinical populations, with consistently acceptable internal consistency coefficients.

Social isolation was assessed using the Lubben Social Network Scale-Revised (LSNS-6), developed by Lubben in 1988 and subsequently revised. The LSNS-6 consists of six items designed to evaluate social connectedness and the size and frequency of contact within family and friendship networks. Participants respond to items assessing perceived availability of social support and regular interpersonal interactions. Scores are calculated by summing responses, with lower scores indicating greater social isolation and weaker social networks. Previous validation studies have confirmed the scale's reliability and validity across different age groups, cultural settings, and community populations.

Self-criticism was measured using the Levels of Self-Criticism Scale (LOSC), developed by Thompson and Zuroff in 2004. The LOSC assesses the tendency to engage in harsh self-evaluation, excessive self-blame, and negative self-judgment. The instrument contains 22 items rated on a seven-point Likert scale ranging from strongly disagree to strongly agree. The scale captures dimensions related to comparative self-criticism and internalized self-criticism. Higher scores reflect stronger self-critical tendencies. Previous psychometric investigations have demonstrated satisfactory convergent validity, discriminant validity, and internal consistency reliability across diverse adult samples.

Intolerance of uncertainty was assessed using the Intolerance of Uncertainty Scale-12 (IUS-12), developed by Carleton, Norton, and Asmundson in 2007. The scale contains 12 items that evaluate emotional, cognitive, and behavioral reactions to uncertain situations and ambiguous future events. Participants rate each statement on a five-point Likert scale ranging from 1 (not at all characteristic of me) to 5 (entirely characteristic of me). Higher scores indicate greater difficulty tolerating uncertainty and unpredictability. Numerous studies have supported the strong psychometric characteristics of the IUS-12, including excellent reliability and robust construct validity across different cultural contexts.

Demographic information was also collected, including age, marital status, educational attainment, employment status, monthly income level, place of residence, and history of mental health treatment. These variables were used to characterize the sample and were examined as potential control variables during exploratory analyses.

2.3. Data Analysis

Data analysis was conducted using Python version 3.12 and relevant machine learning libraries, including PyTorch, Scikit-learn, Pandas, NumPy, and the TabNet framework. Initially, data were screened for missing values, outliers, and inconsistencies. Cases with excessive missing data were excluded, while remaining missing values were handled using multiple imputation procedures. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were calculated to summarize participant characteristics and study variables.

Prior to model development, predictor variables were standardized and examined for multicollinearity using variance inflation factor statistics and correlation matrices. The dataset was randomly divided into training (70%), validation (15%), and testing (15%) subsets. The TabNet model was selected because of its ability to perform sequential attention-based feature selection, enabling improved interpretability and predictive performance for tabular psychological data. The model was trained to predict depression risk scores based on rumination, social isolation, self-criticism, and intolerance of uncertainty.

Hyperparameter optimization was conducted using grid search and cross-validation procedures. Key parameters, including learning rate, batch size, number of decision steps, attention dimensions, and sparsity coefficients, were systematically adjusted to maximize predictive accuracy while minimizing overfitting. Model performance was evaluated using multiple metrics, including coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and mean squared error (MSE).

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Feature importance scores generated by the TabNet architecture were examined to determine the relative contribution of each psychological predictor to depression risk. Additionally, permutation importance analysis and SHAP (Shapley Additive Explanations) values were calculated to provide further insight into the model's decision-making process and enhance interpretability. Statistical significance for supplementary analyses was evaluated at the 0.05 level, and all analyses were conducted using two-tailed testing procedures.

3. Findings and Results

A total of 1,248 women participated in the study and completed all research instruments. Participants ranged in age from 18 to 59 years, with a mean age of 31.84 years (SD = 8.92). Regarding marital status, 42.4% were married, 46.8% were single, 6.7% were divorced, and 4.1% were widowed. In terms of educational attainment, 18.5% had completed secondary education, 29.6% held diploma-level qualifications, 39.7% possessed undergraduate degrees, and 12.2% had postgraduate education. Employment status indicated that 51.3% were employed full-time, 18.9% were employed part-time, 14.7% were self-employed, and 15.1% were unemployed. Approximately 62.8% of participants resided in urban areas, while 37.2% lived in rural communities. Furthermore, 21.4% reported a previous history of psychological counseling or mental health treatment. Examination of PHQ-9 scores revealed that 29.2% of participants demonstrated minimal depression risk, 34.8% exhibited mild depression risk, 23.5% showed moderate depression risk, and 12.5% reported severe levels of depressive symptoms. Preliminary analyses indicated substantial variability across all study variables, suggesting suitability for machine learning modeling and feature importance analysis.

Table 1

Descriptive Statistics and Correlations Among Study Variables

Variable	Mean	SD	1	2	3	4	5
Depression Risk	11.87	6.14	1.00				
Rumination	49.52	10.38	0.71**	1.00			
Social Isolation	14.73	5.21	0.63**	0.58**	1.00		
Self-Criticism	77.84	15.62	0.68**	0.61**	0.54**	1.00	
Intolerance of Uncertainty	39.46	8.17	0.65**	0.59**	0.49**	0.62**	1.00

Table 1 presents the descriptive statistics and Pearson correlation coefficients among the study variables. The findings revealed that depression risk was significantly and positively associated with all predictor variables. The strongest correlation emerged between depression risk and rumination ($r = .71$, $p < .001$), indicating that women who engaged more frequently in repetitive negative thinking reported substantially higher levels of depressive symptoms. Self-criticism also demonstrated a strong positive relationship with depression risk ($r = .68$, $p < .001$), followed by intolerance of uncertainty ($r = .65$, $p < .001$) and social isolation ($r = .63$, $p < .001$). Significant positive correlations were also observed among all predictor variables, suggesting that these psychological vulnerabilities frequently co-occurred within the sample. None of the correlations exceeded the threshold commonly associated with severe multicollinearity, supporting the inclusion of all variables in the predictive modeling process. The magnitude of these associations provided initial evidence that each predictor contributed meaningfully to depression risk among Kenyan women.

Table 2

Predictive Performance of the TabNet Model Across Data Sets

Dataset	R^2	RMSE	MAE	MSE
Training Set	0.874	2.17	1.69	4.71
Validation Set	0.846	2.42	1.88	5.86
Testing Set	0.832	2.58	2.01	6.66

Table 2 summarizes the predictive performance of the TabNet model. Results demonstrated excellent predictive capability across all datasets. In the training sample, the model explained 87.4% of the variance in depression risk

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scores, indicating a strong capacity to learn complex nonlinear relationships among the predictor variables. Importantly, model performance remained highly stable in both the validation and testing datasets. The testing set yielded an R^2 value of .832, suggesting that approximately 83.2% of the variance in depression risk was accurately predicted among previously unseen participants. RMSE and MAE values remained relatively low across all phases of model evaluation, reflecting high prediction accuracy and minimal estimation error. The modest decline in performance from training to testing datasets indicated limited overfitting and strong generalizability. These findings support the effectiveness of the TabNet architecture for identifying women at elevated risk of depression based on cognitive, emotional, and social vulnerability factors.

Table 3

TabNet Feature Importance Scores

Predictor Variable	Importance Score	Relative Importance (%)
Rumination	0.338	33.8
Self-Criticism	0.279	27.9
Intolerance of Uncertainty	0.221	22.1
Social Isolation	0.162	16.2

The feature importance analysis generated by the TabNet model identified rumination as the most influential predictor of depression risk, accounting for 33.8% of the total predictive contribution. This finding suggests that repetitive negative thinking constituted the primary mechanism associated with elevated depressive symptomatology among women in the present sample. Self-criticism emerged as the second most important predictor, contributing 27.9% to model predictions. Women characterized by harsh self-evaluation and persistent self-blame were substantially more likely to experience elevated depression risk. Intolerance of uncertainty ranked third, accounting for 22.1% of predictive importance, indicating that difficulty coping with ambiguity and unpredictable future events played a significant role in depressive vulnerability. Social isolation contributed 16.2% of the model's predictive power and remained an important factor despite ranking fourth. Collectively, these findings indicate that cognitive variables accounted for the majority of explained variance, emphasizing the central role of maladaptive thought processes in depression risk among women.

Table 4

Prediction Accuracy Across Depression Risk Categories

Depression Risk Category	Precision	Recall	F1-Score
Minimal Risk	0.88	0.86	0.87
Mild Risk	0.84	0.83	0.84
Moderate Risk	0.82	0.85	0.83
Severe Risk	0.89	0.91	0.90
Overall Model Performance	0.86	0.86	0.86

The SHAP analysis provided a more detailed understanding of how each predictor influenced model outcomes. The summary plot demonstrated that higher levels of rumination consistently increased predicted depression risk, making it the most influential feature across participants. Elevated self-criticism similarly exerted a strong positive effect on depression predictions, particularly among individuals reporting severe depressive symptoms. Intolerance of uncertainty exhibited a nonlinear influence, with substantial increases in depression risk occurring once moderate levels of uncertainty intolerance were exceeded. Social isolation also contributed positively to depression predictions, although its effects were more variable across participants. The SHAP visualization confirmed the feature importance rankings identified by TabNet and further illustrated the direction and magnitude of predictor effects. Overall, the figure highlighted the dominant role of maladaptive cognitive processes while simultaneously demonstrating the significant contribution of social disconnection to depression vulnerability.

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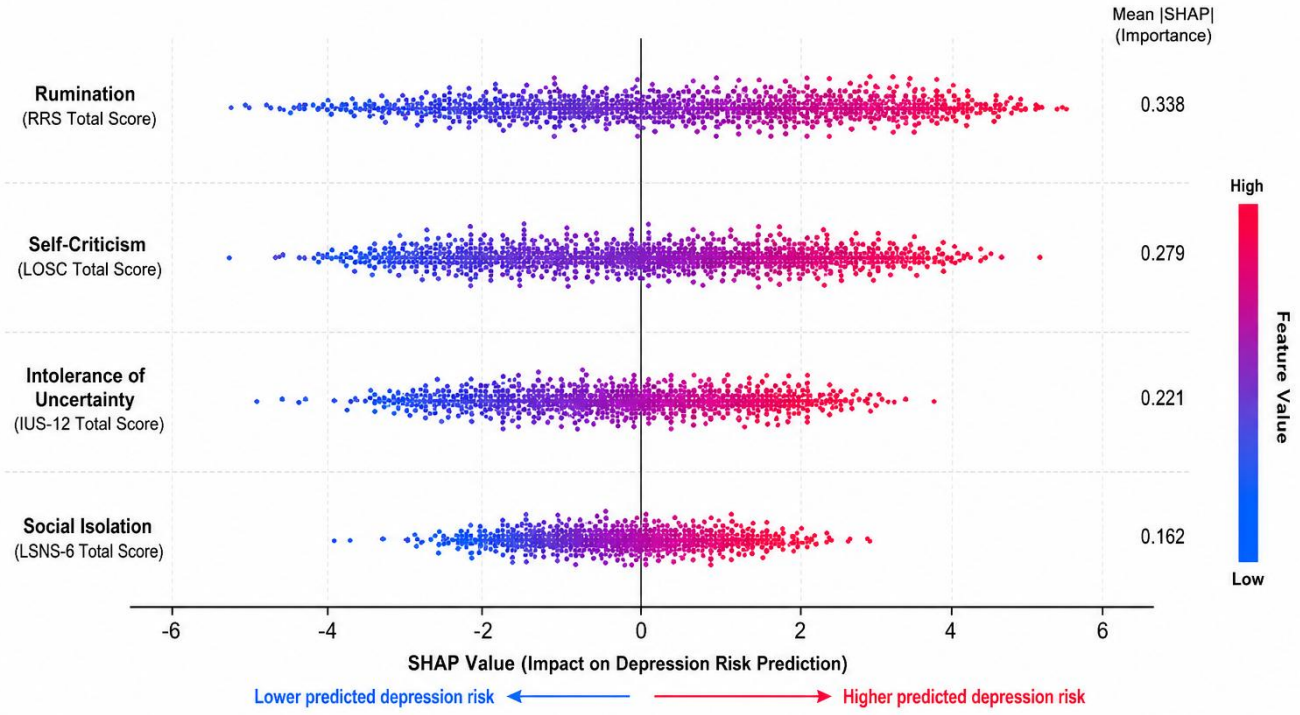
Figure 1

SHAP Summary Plot Illustrating the Relative Contribution of Rumination, Self-Criticism, Intolerance of Uncertainty, and Social Isolation to Depression Risk Predictions



Each dot represents a participant. The position on the x-axis shows the impact of the feature on the prediction (positive values increase depression risk, negative values decrease it), and the color represents the original feature value (red = high, blue = low).

Table 4 presents the classification performance of the TabNet model across different depression risk categories. The model demonstrated high levels of precision, recall, and F1-score across all groups, indicating balanced and reliable classification accuracy. The strongest performance was observed for the severe depression risk category, where precision reached .89 and recall reached .91, resulting in an F1-score of .90. This finding suggests that the model was particularly effective at identifying women who were most vulnerable and potentially in need of clinical intervention. Classification accuracy remained consistently high for minimal, mild, and moderate risk groups, with F1-scores ranging from .83 to .87. The overall model performance yielded an F1-score of .86, demonstrating robust predictive accuracy across the entire sample. These results indicate that the TabNet model not only predicted continuous depression scores effectively but also accurately distinguished between clinically meaningful levels of depression risk, thereby supporting its potential utility as a screening and decision-support tool in mental health settings.

4. Discussion

The present study aimed to predict depression risk among women using rumination, social isolation, self-criticism, and intolerance of uncertainty through an explainable TabNet machine learning model. The findings demonstrated that the proposed model achieved excellent predictive performance, explaining more than 83% of the variance in depression risk within the testing dataset. Moreover, rumination emerged as the most influential predictor, followed by self-criticism, intolerance of uncertainty, and social isolation. The SHAP analysis further confirmed the importance of these variables and revealed their substantial contributions to depression risk predictions. These findings provide support for contemporary transdiagnostic perspectives suggesting that depression develops through the interaction of cognitive, emotional, and interpersonal vulnerabilities rather than through isolated risk factors alone (Flynt et al., 2025; Gerdan & Şalcıoğlu, 2025; Hernández-Posadas et al., 2023).

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One of the most important findings of the study was the superior predictive performance of the TabNet model. The model demonstrated high accuracy across training, validation, and testing datasets, indicating that depression risk among women can be effectively predicted from a combination of psychological and social vulnerability factors. This finding aligns with recent developments emphasizing the usefulness of transdiagnostic predictors for understanding emotional disorders. Contemporary evidence suggests that depression is influenced by multiple interconnected mechanisms that operate simultaneously and often nonlinearly. Traditional statistical approaches frequently examine these relationships independently, whereas machine learning models can capture more complex interactions among predictors. The high predictive power observed in the present study supports the notion that depression risk emerges from the cumulative effects of cognitive and interpersonal vulnerabilities and that advanced machine learning approaches can provide valuable tools for identifying individuals at elevated risk before symptoms become clinically severe (Flynt et al., 2025; Hernández-Posadas et al., 2023; Moreno-Mansilla et al., 2021).

The results identified rumination as the strongest predictor of depression risk. This finding is highly consistent with previous literature demonstrating that repetitive negative thinking plays a central role in the onset, maintenance, and exacerbation of depressive symptoms. Rumination prolongs emotional distress by directing attention toward perceived failures, negative emotions, and unresolved problems while simultaneously reducing the likelihood of adaptive coping and problem-solving behaviors. Women who engage in persistent rumination may become trapped in cycles of negative self-focus that intensify sadness, hopelessness, and emotional exhaustion. The present findings correspond closely with research demonstrating that rumination mediates the impact of stressful experiences and uncertainty on psychological distress. Studies have shown that individuals exposed to uncertainty often engage in repetitive thinking as an attempt to regain cognitive control, yet this strategy paradoxically increases emotional suffering and depressive symptoms (Harrison et al., 2022; Yiğitoğlu et al., 2023; Zhang et al., 2023). Similar evidence has suggested that repetitive negative thinking constitutes a common pathway linking various stressors to depression and anxiety, further supporting the prominent role of rumination observed in the present investigation (Songco et al., 2023; Wu et al., 2025).

Another significant finding was the strong contribution of self-criticism to depression risk. Self-criticism emerged as the second most influential predictor within the model, indicating that harsh self-evaluation substantially increases vulnerability to depressive symptoms among women. This finding can be understood through cognitive theories of depression, which propose that persistent negative self-beliefs contribute to feelings of worthlessness, inadequacy, and hopelessness. Women who consistently judge themselves according to unrealistic standards may become increasingly vulnerable to emotional distress when confronted with perceived failures or interpersonal difficulties. The observed relationship is consistent with studies emphasizing the protective role of self-compassion and adaptive emotional regulation. Research has demonstrated that individuals who treat themselves with kindness and understanding report lower levels of depression and anxiety, whereas those characterized by high levels of self-criticism experience greater emotional distress and poorer psychological adjustment (Cutajar & Bates, 2025; Flynt et al., 2025). The present findings therefore suggest that self-critical cognitive patterns represent a crucial target for interventions designed to reduce depression risk among women.

The study also revealed that intolerance of uncertainty was a powerful predictor of depression risk. This finding is consistent with growing evidence indicating that uncertainty-related distress extends beyond anxiety disorders and contributes substantially to depressive symptomatology. Individuals who perceive uncertainty as threatening often experience chronic worry, cognitive rigidity, and emotional discomfort. Over time, these responses may undermine psychological resilience and increase feelings of helplessness and hopelessness. The current findings support previous studies demonstrating that intolerance of uncertainty predicts both the presence and severity of depressive symptoms across diverse populations. Research has shown that individuals who struggle to tolerate ambiguity are more likely to engage in maladaptive coping strategies, repetitive negative thinking, and emotional avoidance, all of which contribute to depression (Assaf et al., 2025; Choudhary et al., 2023; Gerdan & Şalcıoğlu, 2025). Furthermore, intolerance of uncertainty has been linked to psychological distress among college students, older adults, and community populations exposed to stressful circumstances, highlighting its broad relevance as a transdiagnostic vulnerability factor (Gosselin et al., 2022; İnözü et al., 2022; Nekić, 2023).

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The relationship between intolerance of uncertainty and depression may be particularly important in contemporary societies characterized by rapid social change, economic instability, and constant exposure to uncertain information. Recent research has suggested that uncertainty regarding health, finances, relationships, and future opportunities can contribute significantly to emotional difficulties. Individuals with high intolerance of uncertainty tend to interpret ambiguous situations as threatening and often anticipate negative outcomes, increasing emotional distress and reducing psychological well-being. Studies investigating media-induced uncertainty, pandemic-related concerns, and future-oriented fears have consistently reported associations with depression, loneliness, and psychological dysfunction (Kesner et al., 2025; Kim et al., 2025; Quigley et al., 2022). The present findings reinforce these conclusions and indicate that intolerance of uncertainty remains a crucial predictor of depression risk even when other significant psychological factors are considered simultaneously.

Social isolation also contributed significantly to depression risk, although its predictive importance was somewhat lower than that of the cognitive variables examined. This finding remains highly meaningful because social connectedness is widely recognized as a fundamental determinant of mental health. Women who experience limited social support or reduced interpersonal engagement may be deprived of emotional validation, practical assistance, and opportunities for adaptive coping. Such circumstances can increase vulnerability to loneliness, emotional distress, and depressive symptoms. The present findings are consistent with studies demonstrating that social isolation and loneliness represent robust predictors of poor psychological outcomes across diverse populations. Research conducted during periods of social disruption has repeatedly shown that reduced social interaction is associated with increased depression, anxiety, stress, and reduced well-being (Muls et al., 2022; Phillips et al., 2023; Zsidó et al., 2022).

Importantly, the relatively lower ranking of social isolation compared with rumination and self-criticism should not be interpreted as evidence that social factors are less important. Rather, the findings suggest that social experiences may influence depression partly through their effects on cognitive processes. Previous studies have demonstrated that loneliness and reduced social support contribute to repetitive negative thinking and emotional distress. Individuals who lack supportive relationships may have fewer opportunities to challenge maladaptive cognitions, resulting in increased rumination and self-critical thinking. This interpretation is consistent with evidence indicating that loneliness mediates the relationship between social support and mental health outcomes and that social isolation frequently operates alongside cognitive vulnerabilities rather than independently of them (Harrison et al., 2022; Kim et al., 2025; Zhuo et al., 2021).

The SHAP analysis provided additional insight into the mechanisms underlying depression risk. The visualization demonstrated that higher levels of rumination, self-criticism, intolerance of uncertainty, and social isolation consistently increased predicted depression scores. These findings support contemporary transdiagnostic models proposing that emotional disorders arise from interconnected systems of maladaptive cognition, emotional dysregulation, and interpersonal difficulties. Similar conclusions have been reported in systematic reviews highlighting the central role of repetitive negative thinking, uncertainty-related distress, and emotional vulnerabilities across multiple forms of psychopathology (Gerdan & Şalcıoğlu, 2025; Hernández-Posadas et al., 2023). The consistency of the SHAP results further strengthens confidence in the robustness and interpretability of the predictive model.

Another noteworthy aspect of the findings concerns the apparent convergence of multiple transdiagnostic risk factors. Rather than identifying a single dominant cause of depression, the model revealed that depression risk was best understood as the result of several interacting vulnerabilities. This observation is consistent with contemporary perspectives emphasizing that psychological disorders rarely emerge from isolated factors. Instead, depression appears to develop when maladaptive cognitive styles, emotional vulnerabilities, and social challenges combine to overwhelm an individual's coping resources. Similar conclusions have been reported in studies examining emotional distress across different populations and contexts, suggesting that integrated models of risk provide a more accurate representation of psychological functioning than single-factor explanations (Flynt et al., 2025; Hernández-Posadas et al., 2023; Moreno-Mansilla et al., 2021).

5. Conclusion

Overall, the findings contribute to the growing literature supporting transdiagnostic conceptualizations of depression and demonstrate the value of explainable machine learning approaches in mental health research. By simultaneously examining rumination, self-criticism, intolerance of

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uncertainty, and social isolation, the study provides a comprehensive account of psychological risk factors associated with depression among women. The results indicate that cognitive vulnerabilities represent particularly powerful predictors while also highlighting the important role of interpersonal experiences in shaping emotional well-being. Collectively, these findings offer both theoretical and practical insights for improving the identification and prevention of depression in women.

6. Limitations and Suggestions

Several limitations should be acknowledged when interpreting the findings. First, the cross-sectional design prevents causal conclusions regarding the relationships among the study variables. Although the model successfully predicted depression risk, it cannot determine whether the identified predictors directly caused depressive symptoms. Second, all variables were assessed using self-report questionnaires, which may be influenced by social desirability bias, response styles, and subjective interpretation. Third, the sample consisted exclusively of women from Kenya, which may limit the generalizability of the findings to men or individuals from other cultural contexts. Fourth, additional variables known to influence depression, such as childhood adversity, trauma history, personality traits, and socioeconomic stressors, were not included in the model. Finally, despite the strong predictive performance of TabNet, machine learning models remain dependent on the quality and representativeness of the available data.

Future studies should employ longitudinal designs to examine causal relationships and determine how changes in rumination, self-criticism, social isolation, and intolerance of uncertainty influence depression over time. Researchers may also investigate additional psychological and environmental predictors to develop more comprehensive predictive models. Comparative studies involving different cultural groups, age cohorts, and genders would help establish the generalizability of the findings. Future investigations could evaluate whether intervention-induced reductions in the identified risk factors lead to corresponding decreases in depression risk. Moreover, researchers should continue exploring advanced explainable artificial intelligence methods to improve the transparency, accuracy, and clinical applicability of psychological prediction models.

Mental health professionals should prioritize the assessment of rumination, self-criticism, intolerance of uncertainty, and social isolation when evaluating depression risk among women. Prevention programs may benefit from incorporating cognitive restructuring techniques designed to reduce repetitive negative thinking and harsh self-evaluation. Interventions aimed at increasing tolerance for uncertainty and enhancing psychological flexibility may also contribute to improved emotional well-being. Community-based initiatives that strengthen social support networks and reduce social isolation could provide additional protection against depression. Finally, healthcare systems may consider integrating explainable machine learning tools into screening and early intervention programs to facilitate timely identification of women at elevated risk for depression and to support personalized mental health care planning.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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