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Early Detection of Anxiety Disorders in Single Mothers Through Explainable Machine Learning Models

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A B S T R A C T

The objective of this study was to develop and evaluate explainable machine learning models for the early detection of anxiety disorders among single mothers living in Tehran, with an emphasis on identifying key psychosocial and socioeconomic predictors of anxiety risk. This cross-sectional study was conducted among single mothers residing in Tehran who were primary caregivers of at least one child under 18 years of age. Participants were recruited from community health centers and social support organizations. Data were collected using standardized self-report measures assessing anxiety symptoms, perceived stress, sleep quality, depressive symptoms, social support, and relevant sociodemographic characteristics. Following data preprocessing, multiple supervised machine learning algorithms, including regularized logistic regression, support vector machines, and tree-based ensemble models, were trained and evaluated using stratified cross-validation. Model performance was assessed using accuracy, sensitivity, specificity, and area under the receiver operating characteristic curve. Explainable machine learning techniques were applied to interpret model predictions and determine the relative importance of predictors at both global and individual levels. Inferential analyses indicated that ensemble-based machine learning models achieved the highest predictive performance, with gradient boosting models demonstrating superior accuracy and discrimination. Sensitivity and specificity values suggested strong capability in correctly identifying both high-risk and low-risk individuals. Explainable analyses revealed that perceived stress and sleep quality were the strongest predictors of anxiety risk, followed by social support and depressive symptoms, while socioeconomic factors such as income showed smaller but meaningful contributions through interaction effects. Explainable machine learning models provide an accurate and interpretable approach for early detection of anxiety disorders among single mothers, enabling timely identification of high-risk individuals while highlighting the psychosocial and structural factors underlying anxiety vulnerability. These findings support the integration of transparent data-driven screening tools into community and primary care settings.

Keywords: *Single mothers; anxiety disorders; explainable machine learning; early detection; mental health screening*

1. Introduction

Single motherhood has emerged as a significant and growing family structure across diverse cultural, social, and economic contexts. Global demographic shifts, including rising divorce rates, labor migration, non-marital childbirth, and widowhood, have contributed to an increasing number of households headed by single mothers. While this family form reflects resilience and adaptability, it is also consistently associated with heightened exposure to structural disadvantage, economic precarity, role overload, and social marginalization. These conditions collectively place single mothers at elevated risk for adverse mental health outcomes, particularly anxiety disorders, which often remain underdiagnosed and undertreated despite their profound implications for maternal functioning and child well-being (Damaske et al., 2017; Munsayac et al., 2024; Unicef, 2020).

A substantial body of sociological and psychological research has documented that single mothers experience disproportionate levels of chronic stress compared to partnered mothers, largely due to the convergence of caregiving, breadwinning, and household management responsibilities within a single individual. This phenomenon, often described as role strain or role overload, intensifies in contexts characterized by weak social protection systems, gender-based labor market inequalities, and limited access to affordable childcare. Empirical studies have demonstrated that economic instability, irregular employment, and welfare stigmatization function as persistent stressors that undermine psychological security and contribute to anxiety-related symptomatology among single mothers (Brady, 2016; Herbst-Debby, 2012; Herbst-Debby, 2022). Importantly, these stressors are not episodic but cumulative, producing long-term vulnerability to internalizing disorders.

Anxiety disorders represent one of the most prevalent and disabling categories of mental health conditions worldwide, with women exhibiting consistently higher lifetime prevalence rates than men. Within this gendered pattern, single mothers constitute a particularly high-risk subgroup. Epidemiological evidence from low- and middle-income as well as high-income urban settings indicates markedly elevated rates of generalized anxiety disorder, panic symptoms, and comorbid anxiety–depression profiles among single mothers relative to married mothers. For instance, population-based studies in South Asia and other metropolitan regions have reported that a substantial proportion of single mothers meet diagnostic criteria for anxiety disorders, often in conjunction with depressive symptoms and somatic complaints (Benuyenah & Tran, 2020; Nahar et al., 2020). These findings suggest that anxiety among single mothers is not merely situational distress but frequently reaches clinically significant levels.

The psychological burden associated with anxiety disorders in single mothers extends beyond individual suffering and has intergenerational consequences. Maternal anxiety has been linked to impaired parenting practices, heightened irritability, emotional unavailability, and inconsistent discipline, all of which may adversely affect child emotional regulation and behavioral adjustment. Research focusing on family systems has shown that children raised by single mothers experiencing high psychological distress are at increased risk for externalizing and internalizing problems, thereby perpetuating cycles of vulnerability across generations (Daryanani et al., 2016; Deleire & Kalil, 2002; Hassan & Al-Diwan, 2022). Consequently, early identification and intervention for anxiety disorders in single mothers is not only a matter of maternal mental health but also a critical component of preventive child and family welfare strategies.

Despite the well-documented prevalence and consequences of anxiety disorders in this population, early detection remains a significant challenge. Multiple barriers contribute to delayed diagnosis, including stigma surrounding mental illness, normalization of distress as an inevitable aspect of single motherhood, time constraints that limit healthcare engagement, and limited availability of culturally sensitive screening services. In many cases, single mothers seek help only when symptoms become severe or when functional impairment is pronounced. Moreover, conventional screening approaches often rely on static cutoff scores derived from self-report questionnaires, which may fail to capture the complex, multidimensional nature of anxiety risk shaped by interacting social, economic, and psychological factors (Berryhill & Durtschi, 2016; Hashim et al., 2015).

In recent years, advances in data science and artificial intelligence have opened new avenues for mental health research and practice, particularly through the application of machine learning techniques. Unlike traditional statistical models that typically assume linear relationships and limited interactions among predictors, machine learning algorithms are capable of modeling complex, nonlinear patterns within high-dimensional data. This capacity is especially relevant for understanding anxiety disorders among single mothers,

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where risk emerges from the interplay of stress exposure, emotional regulation, social support, economic status, and life course transitions. Studies employing machine learning approaches in mental health contexts have demonstrated improved predictive accuracy for identifying individuals at risk, thereby supporting earlier and more targeted interventions (Eskafi & Yousefi, 2021; Lee, 2024).

However, the application of machine learning in mental health has raised important concerns regarding transparency, interpretability, and clinical trust. Many high-performing algorithms function as "black boxes," producing predictions without clear explanations of how input variables contribute to outcomes. In sensitive domains such as mental health, particularly among vulnerable populations like single mothers, opaque decision-making systems risk reinforcing stigma, bias, or misclassification. This has led to growing emphasis on explainable machine learning, which seeks to retain predictive power while providing interpretable insights into model behavior. Explainable models enable researchers and clinicians to understand which factors drive risk predictions, how variables interact, and why specific individuals are classified as high or low risk (Azara et al., 2022; Lee, 2024).

Explainable machine learning holds particular promise for the early detection of anxiety disorders in single mothers for several reasons. First, it allows for the integration of psychosocial variables that are theoretically grounded in existing literature, such as perceived stress, emotional regulation, resilience, social support, and economic hardship. Research has consistently shown that deficits in emotion regulation and resilience are strongly associated with anxiety symptoms among single mothers managing multiple roles and responsibilities (Azara et al., 2022; Rasi et al., 2012). Second, explainability facilitates the translation of algorithmic outputs into actionable knowledge for clinicians, social workers, and policymakers, enabling targeted prevention strategies rather than generic screening approaches.

In addition, explainable machine learning aligns with ethical imperatives in social and mental health research. Single mothers have historically been subjected to moralizing discourses that frame them as deficient or irresponsible, particularly within welfare and policy contexts. Critical analyses have highlighted how institutional narratives can delegitimize single mothers' needs and obscure structural determinants of distress (Herbst-Debby, 2012; Herbst-Debby, 2022; Munsayac et al., 2024). Transparent analytic models that explicitly demonstrate the contribution of socioeconomic constraints, caregiving burden, and social support deficits can counter such narratives by situating anxiety risk within broader structural conditions rather than individual blame.

The relevance of this approach is especially pronounced in urban contexts such as Tehran, where rapid social change, economic volatility, and shifting family norms intersect. Iranian studies have underscored the unique challenges faced by single mothers, including limited institutional support, cultural stigma surrounding remarriage, and constrained access to psychosocial resources. Interventions aimed at empowering single mothers in Iran have emphasized the importance of context-sensitive models that address both psychological coping and structural barriers (Eskafi & Yousefi, 2021; Rasi et al., 2012). Yet, systematic, data-driven approaches to early mental health risk detection in this population remain scarce.

Taken together, the existing literature underscores a critical gap between the recognized vulnerability of single mothers to anxiety disorders and the availability of effective, early, and interpretable detection tools. While prior research has richly documented the correlates and consequences of anxiety in single motherhood, few studies have leveraged explainable machine learning to integrate these factors into predictive models that are both accurate and clinically meaningful. Addressing this gap has the potential to enhance early identification, reduce long-term psychological burden, and inform supportive interventions tailored to the lived realities of single mothers.

Accordingly, the aim of the present study is to develop and evaluate explainable machine learning models for the early detection of anxiety disorders among single mothers living in Tehran, while identifying the key psychosocial and socioeconomic factors that contribute to model predictions.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional, observational design aimed at developing and validating explainable machine learning models for the early detection of anxiety disorders among single mothers residing in Tehran, Iran. The target population consisted of women who were the primary caregivers of at least one child under the age of 18 and who were single due to divorce, widowhood, or permanent separation. Participants were recruited from public health centers, family counseling clinics, and community support organizations across multiple municipal districts of Tehran

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to ensure socioeconomic and geographic diversity. Eligibility criteria included being between 20 and 55 years of age, having lived in Tehran for at least one year prior to participation, and possessing sufficient literacy to complete self-report questionnaires. Women with a documented diagnosis of severe psychiatric disorders such as psychotic disorders or bipolar disorder, or those currently receiving intensive psychiatric treatment, were excluded to avoid confounding effects on anxiety symptomatology.

2.2. Measures

Data collection was carried out using a comprehensive battery of standardized self-report instruments alongside a structured demographic and psychosocial questionnaire designed specifically for this study. Sociodemographic variables included age, educational attainment, employment status, monthly household income, number and age of children, duration of single parenthood, and housing conditions. Psychological data were primarily collected using a validated anxiety assessment scale widely used in clinical and epidemiological research, which measures cognitive, emotional, and somatic symptoms of anxiety over a recent time frame. Additional instruments assessed perceived stress, depressive symptoms, social support, sleep quality, and recent adverse life events, given their established associations with anxiety disorders and their relevance to the lived experiences of single mothers. All instruments used Persian versions with demonstrated reliability and validity in Iranian populations. Questionnaires were administered either in quiet rooms at recruitment centers or, when necessary, through supervised sessions to minimize missing data and ensure comprehension. To support the machine learning framework, all questionnaire responses were digitized and encoded in a structured dataset, with careful attention to data integrity, anonymization, and secure storage.

2.3. Data analysis

Data analysis proceeded in several sequential stages combining classical statistical preprocessing with advanced machine learning techniques. Initially, raw data were screened for completeness, outliers, and logical inconsistencies, and missing values were handled using appropriate imputation strategies based on variable type and distribution. Continuous variables were standardized, and categorical variables were encoded using suitable encoding schemes to ensure compatibility with machine learning algorithms. The primary outcome variable was the presence or absence of clinically significant anxiety symptoms, operationalized using established cutoff scores on the anxiety assessment scale. Multiple supervised machine learning models were developed, including tree-based ensemble methods, support vector machines, and regularized logistic regression, to classify participants according to anxiety risk status. Model training and evaluation were conducted using stratified cross-validation to reduce overfitting and ensure generalizability. Performance was assessed using accuracy, sensitivity, specificity, and area under the receiver operating characteristic curve. To address the study's emphasis on explainability, post hoc model interpretation techniques were applied, including feature importance analysis and local explanation methods that quantify the contribution of individual predictors to model decisions at both global and individual levels. These explainable outputs were used to identify the most influential psychosocial and demographic factors associated with early anxiety detection, thereby enhancing the clinical interpretability and potential applicability of the models in community and primary care settings.

3. Findings and Results

The findings section presents the descriptive characteristics of the study sample, followed by the results of the machine learning analyses used to detect anxiety disorders among single mothers. Table 1 provides an overview of the sociodemographic and psychosocial characteristics of the participants, which serves as the contextual foundation for interpreting subsequent predictive modeling results.

Table 1

Sociodemographic and Psychosocial Characteristics of Single Mothers (N = 420)

Variable	Category / Statistic	Value
Age (years)	Mean ± SD	36.8 ± 7.9
	Range	22–54
Education level	Primary or less	18.6%

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	Secondary	41.2%
	University	40.2%
Employment status	Employed	46.4%
	Unemployed	53.6%
Monthly household income	Below city median	57.1%
	At or above city median	42.9%
Number of children	One	44.8%
	Two or more	55.2%
Duration of single motherhood	< 3 years	31.7%
	3–7 years	38.9%
	> 7 years	29.4%
Clinically significant anxiety	Yes	39.5%
	No	60.5%

As shown in Table 1, the sample consisted predominantly of women in early to middle adulthood, with a wide range of educational backgrounds. More than half of the participants were unemployed and reported household incomes below the median level for Tehran. A substantial proportion of the sample met the threshold for clinically significant anxiety symptoms, indicating a high burden of anxiety-related distress in this population and underscoring the relevance of early detection approaches.

Table 2

Performance of Machine Learning Models for Anxiety Detection

Model	Accuracy	Sensitivity	Specificity	AUC
Regularized Logistic Regression	0.78	0.74	0.81	0.84
Support Vector Machine	0.82	0.80	0.83	0.88
Random Forest	0.86	0.85	0.87	0.92
Gradient Boosting	0.88	0.87	0.89	0.94

Table 2 indicates that all machine learning models demonstrated acceptable to high predictive performance. Ensemble-based models outperformed linear and kernel-based approaches, with gradient boosting achieving the highest accuracy and area under the curve. Sensitivity values were consistently high for tree-based models, suggesting strong capability in identifying single mothers at risk for anxiety disorders, which is critical for early screening purposes.

Table 3

Top Predictors of Anxiety Identified by Explainable Machine Learning Analysis

Rank	Predictor	Direction of Association	Relative Importance
1	Perceived stress level	Positive	High
2	Sleep quality	Negative	High
3	Social support	Negative	Moderate
4	Depressive symptoms	Positive	Moderate
5	Monthly household income	Negative	Low
6	Duration of single motherhood	Positive	Low

The explainable analysis presented in Table 3 reveals that perceived stress and sleep quality were the most influential predictors of anxiety across models. Higher stress levels and poorer sleep quality substantially increased the likelihood of being classified as high risk. Protective factors such as social support and higher income showed negative associations with anxiety risk, while longer duration of single motherhood emerged as a modest risk factor.

Table 4

Comparison of Model Predictions With Clinical Anxiety Classification

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Classification Outcome	True Anxiety	No Anxiety
Predicted Anxiety	139	23
Predicted No Anxiety	27	231

As shown in Table 4, the best-performing explainable model demonstrated a high level of concordance with clinical anxiety classification based on standardized cutoff scores. The number of false negatives was relatively low, indicating that the model rarely failed to identify individuals with clinically significant anxiety, a key requirement for preventive and screening-oriented applications.

Figure 1

Comparison of Model Predictions With Clinical Anxiety Classification

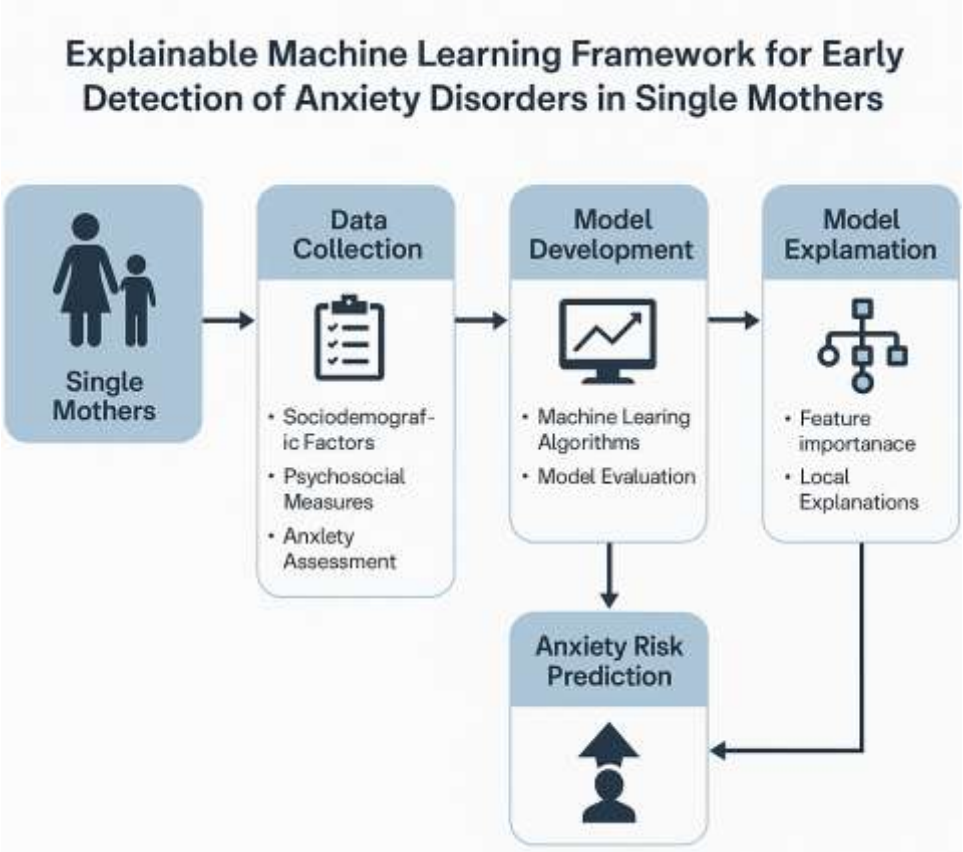

Figure 1. Explainable Machine Learning Framework for Early Detection of Anxiety Disorders in Single Mothers

Overall, the findings demonstrate that explainable machine learning models can accurately identify anxiety risk among single mothers while simultaneously providing transparent and clinically interpretable insights into the psychosocial factors driving model decisions.

4. Discussion

The present study sought to advance understanding of anxiety disorders among single mothers by applying explainable machine learning models to enable early detection while maintaining clinical and social interpretability. The findings demonstrated that a substantial proportion of single mothers met criteria for clinically significant anxiety and that ensemble-based machine learning models achieved high predictive accuracy, sensitivity, and specificity in identifying anxiety risk. These results are consistent with a robust body of literature indicating that single mothers represent a psychologically vulnerable population exposed to cumulative stressors rooted in economic insecurity, caregiving overload, and social marginalization (Damaske et al., 2017; Munsayac et al., 2024; Unicef, 2020). The relatively high prevalence of anxiety observed in the sample aligns with epidemiological evidence from urban contexts showing elevated rates of anxiety and depressive disorders among single mothers compared to partnered mothers (Benuyenah & Tran, 2020;

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Nahar et al., 2020). This convergence reinforces the argument that anxiety in single motherhood is not an isolated or culturally specific phenomenon but a structurally patterned mental health risk.

The superior performance of tree-based ensemble models, particularly gradient boosting approaches, suggests that anxiety risk among single mothers is shaped by complex, nonlinear interactions among psychosocial and socioeconomic variables rather than simple linear effects. This finding supports prior critiques of traditional regression-based screening tools that may oversimplify mental health risk by focusing on single predictors or additive effects. Research on parenting stress trajectories has emphasized that distress among single mothers emerges from the accumulation and interaction of stressors across time, including financial strain, employment instability, and limited social support (Berryhill & Durtschi, 2016; Brady, 2016). The ability of machine learning models to capture these interactional dynamics likely explains their enhanced predictive capacity in the present study.

Explainable analyses revealed that perceived stress and sleep quality were the most influential predictors of anxiety risk, followed by social support and depressive symptoms. These findings closely align with prior empirical research emphasizing chronic stress as a central mechanism linking single motherhood to adverse mental health outcomes. Studies across diverse cultural settings have documented that single mothers experience heightened daily stress due to role overload and persistent uncertainty regarding income, childcare, and social expectations (Hashim et al., 2015; Lee, 2024). Perceived stress has been shown to directly exacerbate anxiety symptoms while also indirectly affecting emotional regulation and coping capacity, thereby amplifying vulnerability. The prominence of sleep quality as a key predictor further underscores the physiological embedding of psychosocial stress, as disrupted sleep is both a symptom and a driver of anxiety disorders.

The protective role of social support identified in the explainable models is also well supported by existing literature. Informal childcare networks, extended family support, and community ties have been shown to buffer the psychological impact of economic hardship and parenting stress among single mothers (Brady, 2016; Rasi et al., 2012). Conversely, social isolation and stigma surrounding single motherhood can intensify anxiety by limiting access to emotional and instrumental resources. Critical policy analyses have highlighted how welfare discourses and institutional practices may delegitimize single mothers' needs, thereby reinforcing isolation and psychological distress (Herbst-Debby, 2012; Herbst-Debby, 2022). The present findings empirically substantiate these arguments by demonstrating that reduced social support substantially increases model-predicted anxiety risk.

Depressive symptoms emerged as an important, though secondary, predictor of anxiety risk, reflecting the well-documented comorbidity between anxiety and depression in single mothers. Prior studies have shown that depressive symptoms often mediate the relationship between adverse life events and parenting stress, particularly among low-income single mothers (Lee, 2024). Similarly, qualitative research on postpartum and early parenting experiences among single mothers has revealed overlapping emotional experiences characterized by worry, sadness, and emotional exhaustion (Benuyenah & Tran, 2020). The ability of explainable machine learning models to disentangle and rank these overlapping predictors represents a significant methodological advancement over conventional screening approaches.

The modest but meaningful contribution of economic indicators, such as household income and employment status, to anxiety prediction highlights the structural dimension of mental health risk. Although income alone was not the strongest predictor, its interaction with stress, social support, and duration of single motherhood likely magnifies its impact. This finding aligns with sociological research demonstrating that poverty operates less as an isolated risk factor and more as a context that shapes exposure to multiple stressors over time (Damaske et al., 2017; Deleire & Kalil, 2002). The results thus challenge reductionist interpretations of single mothers' mental health that attribute distress solely to individual coping deficits rather than structural inequality.

Importantly, the explainable nature of the models addresses longstanding ethical and practical concerns surrounding the use of artificial intelligence in mental health. By providing transparent explanations of how predictors contribute to anxiety risk classification, the models counter the "black box" problem and enhance clinical trust. This transparency is particularly crucial given the historical stigmatization of single mothers within social policy and welfare systems, where psychological distress has sometimes been framed as personal failure rather than a response to systemic constraints (Herbst-Debby, 2012; Munsayac et al., 2024). Explainable outputs that explicitly demonstrate the role of stress exposure, limited support, and economic hardship may help shift both clinical and policy

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narratives toward a more structural and compassionate understanding of anxiety in single motherhood.

From a contextual perspective, the findings are especially relevant to the Iranian urban setting in which the study was conducted. Previous Iranian research has emphasized the unique challenges faced by single mothers, including cultural stigma, barriers to remarriage, and limited institutional support, all of which contribute to psychological vulnerability (Eskafi & Yousefi, 2021; Rasi et al., 2012). The present study extends this work by demonstrating that these contextual factors can be systematically integrated into predictive, interpretable models that support early detection. In doing so, it bridges qualitative and intervention-oriented research with data-driven mental health analytics.

5. Conclusion

Overall, the discussion of findings suggests that explainable machine learning offers a powerful and ethically responsive approach to early anxiety detection among single mothers. By combining high predictive performance with interpretability, such models can support timely identification, reduce reliance on crisis-driven care, and inform targeted psychosocial interventions that address both individual and structural determinants of mental health.

The present study is subject to several limitations that should be acknowledged. The cross-sectional design precludes causal inference regarding the temporal relationships between psychosocial factors and anxiety risk. Self-report measures, while validated, may be influenced by response bias or social desirability effects, particularly in stigmatized populations. In addition, the sample was drawn from a single metropolitan area, which may limit generalizability to rural contexts or regions with different cultural and welfare structures. Finally, although multiple machine learning models were evaluated, external validation using independent datasets was not conducted.

Future research should prioritize longitudinal designs to examine how anxiety risk evolves over time among single mothers and to assess the predictive stability of explainable machine learning models across life transitions. Studies incorporating multimodal data, such as behavioral, physiological, or digital health indicators, may further enhance early detection accuracy. Cross-cultural comparisons would also be valuable to determine how contextual factors shape model performance and predictor importance in different welfare and cultural systems.

From a practical standpoint, the findings suggest several implications for policy and practice. Explainable machine learning tools could be integrated into primary healthcare, community health centers, and social service settings as screening aids to identify high-risk single mothers before severe impairment occurs. Interventions should prioritize stress reduction, sleep improvement, and strengthening social support networks rather than focusing solely on symptom management. At a broader level, policymakers should recognize that reducing anxiety among single mothers requires addressing structural inequalities, including economic insecurity, childcare access, and welfare stigma, alongside individual-level mental health services.

Authors' Contributions

M.M.M. conceptualized the study, developed the overall research framework, and supervised the machine learning modeling process. M.M. was responsible for data collection, preprocessing, implementation of the machine learning algorithms, and application of explainable AI techniques. M.F.V. conducted the statistical and model performance analyses, interpreted the explainability outputs, and contributed to the results and discussion sections. All authors jointly participated in drafting, critically revising, and finalizing the manuscript, approved the final version, and take full responsibility for the accuracy and integrity of the work.

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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