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Explainable AI Forecast of Psychological Distress in Adolescents Based on Family Conflict, School Pressure, and Emotion Regulation Capacity

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A B S T R A C T

Objective: The objective of this study was to develop and interpret an explainable artificial intelligence model for forecasting psychological distress in adolescents by quantifying the joint and individual contributions of family conflict, school pressure, and emotion regulation capacity.

Methods and Materials: This cross-sectional study was conducted among 1,142 secondary school students aged 13–18 years in Germany using multi-stage cluster sampling. Participants completed validated self-report measures of psychological distress, family conflict, school pressure, and emotion regulation capacity. Data were analyzed using an explainable gradient boosting machine learning framework with five-fold cross-validation. Model performance was evaluated using root mean square error, mean absolute error, and coefficient of determination. Feature contributions and interaction effects were examined using Shapley Additive Explanations and partial dependence analyses to ensure full interpretability of predictions.

Findings: The explainable model demonstrated strong predictive accuracy, accounting for 69% of the variance in adolescent psychological distress on the test dataset ($R^2 = 0.69$, RMSE = 3.58, MAE = 2.71). Feature attribution analysis revealed that school pressure was the most influential predictor (36.2% relative contribution), followed by emotion regulation capacity (31.1%) and family conflict (24.7%), while demographic variables showed minimal impact. Interaction analyses indicated that high emotion regulation capacity substantially attenuated the negative effects of elevated school pressure and family conflict on psychological distress.

Conclusion: Adolescent psychological distress is primarily shaped by the combined influence of academic stress, family dynamics, and emotional self-regulation. Explainable artificial intelligence provides a powerful and transparent framework for identifying individualized risk profiles and informing targeted mental health interventions in educational and clinical settings.

Keywords: *Adolescent mental health; psychological distress; explainable artificial intelligence; emotion regulation; family conflict; school pressure.*

1. Introduction

Adolescent psychological distress has emerged as a critical public health concern across global contexts, with increasing prevalence and complexity driven by rapid social, technological, and educational transformations. Contemporary adolescents face unprecedented emotional challenges rooted in academic competition, family instability, digital immersion, social isolation, and heightened performance expectations. Large-scale international studies consistently document rising levels of anxiety, depression, and stress symptoms among youth, positioning adolescent mental health as one of the most urgent priorities in current psychological and educational research (Hawes et al., 2021; Torales et al., 2025; Yani et al., 2025). The COVID-19 pandemic further intensified these trends, amplifying vulnerabilities within family systems, school environments, and peer networks, while simultaneously disrupting traditional support mechanisms (Russell et al., 2020; Silk et al., 2021; Spinelli et al., 2020). Consequently, there is growing recognition that adolescent psychological distress must be understood as a multidimensional phenomenon shaped by dynamic interactions among individual regulatory capacities, family functioning, and school-related stressors.

Among the environmental contributors to adolescent distress, family conflict occupies a central role. The family context constitutes the primary emotional and developmental environment for youth, and disturbances within this system significantly heighten vulnerability to internalizing symptoms. Empirical evidence demonstrates that dysfunctional parent–child interactions, poor communication quality, and chronic family conflict undermine emotional security and adaptive coping, thereby increasing the risk of anxiety, depression, and stress-related disorders (Gautam et al., 2024; Lanjekar et al., 2022; Pu & Rodriguez, 2023). During periods of societal crisis, such as the pandemic, parental stress and family tension intensified, further exacerbating adolescents' psychological burden (Keleynikov et al., 2024; Russell et al., 2020; Spinelli et al., 2020). Longitudinal and mediation models confirm that family dynamics influence adolescent mental health both directly and indirectly through emotional regulation processes and perceived social support (Karam et al., 2023; LaMontagne et al., 2022; Ye et al., 2022). These findings highlight family conflict as not merely a contextual stressor but a core psychological determinant of adolescent well-being.

Parallel to family influences, school pressure represents a dominant institutional stressor in adolescent life. Academic demands, performance evaluation, examination anxiety, and perceived expectations from teachers and parents collectively generate substantial psychological load. Educational systems increasingly emphasize competitiveness and achievement metrics, which amplify stress exposure and emotional strain among students. Extensive research confirms that academic stress is strongly associated with depressive symptoms, anxiety disorders, emotional exhaustion, and school refusal behaviors (Fujita et al., 2022; Rohrig et al., 2023; Uzun et al., 2024; Vincenzo et al., 2024). School-based stressors have been linked to broader psychosocial dysfunction, including peer difficulties, diminished self-efficacy, and maladaptive coping strategies (Källmén & Hallgren, 2021; Vacca et al., 2023). Importantly, recent intervention studies demonstrate that structured school programs targeting stress management and emotional skills significantly improve adolescent mental health outcomes, underscoring the causal role of school pressure in shaping psychological trajectories (Giridharan & Pandiyan, 2024; Khunti et al., 2022; Ratnam et al., 2022).

While environmental stressors are powerful predictors of adolescent distress, individual emotion regulation capacity constitutes a fundamental psychological mechanism that shapes how youth interpret, manage, and respond to stress. Emotion regulation refers to the ability to monitor, evaluate, and modify emotional reactions in adaptive ways, enabling individuals to maintain psychological equilibrium in the face of adversity. Robust evidence indicates that deficits in emotion regulation predict higher levels of depression, anxiety, and stress, whereas effective regulatory strategies confer resilience and psychological protection (Brites et al., 2023; Renati et al., 2023; Tanguy et al., 2024). Emotion regulation mediates the impact of family conflict, academic stress, and social adversity on adolescent mental health, positioning it as a central hub within the stress–psychopathology network (LaMontagne et al., 2022; Ye et al., 2022; Zapata & Onwuegbuzie, 2022). Moreover, maladaptive cognitive emotion regulation has been shown to intensify the negative effects of bullying, social rejection, and academic failure, whereas adaptive strategies promote recovery and long-term well-being (Martínez-Lorca et al., 2022; Vacca et al., 2023).

Recent research further demonstrates that emotion regulation interacts with interpersonal processes, including co-rumination and peer support, in shaping distress trajectories. While peer disclosure can foster emotional

JAYPS
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relief, excessive co-rumination amplifies negative affect and prolongs distress, particularly among adolescents with limited regulatory skills (Steffie van der Mey- et al., 2025; Stone et al., 2022). These interactive dynamics underscore that adolescent distress emerges not from isolated risk factors but from complex, reciprocal systems linking family, school, peer contexts, and individual regulatory capacity.

Despite substantial progress in identifying key determinants of adolescent psychological distress, existing research remains constrained by traditional statistical modeling approaches that often assume linearity, independence of predictors, and homogeneity of effects across individuals. Such assumptions fail to capture the intricate nonlinear interactions and heterogeneous pathways through which distress develops. Adolescents differ profoundly in how they experience family conflict, interpret school pressure, and deploy emotion regulation strategies, necessitating analytical frameworks capable of modeling these individualized processes with precision.

Explainable artificial intelligence (XAI) offers transformative potential for advancing psychological research by enabling highly accurate predictive modeling while preserving interpretability of results. Machine learning methods, particularly ensemble models, outperform conventional regression techniques in handling complex nonlinear relationships and high-dimensional data. However, their clinical and scientific adoption historically suffered from limited transparency. The emergence of explainable AI frameworks resolves this limitation by allowing researchers to quantify feature contributions, identify individualized risk profiles, and visualize interaction effects in psychologically meaningful terms. Such capabilities are particularly valuable for adolescent mental health research, where ethical responsibility demands both predictive accuracy and conceptual clarity.

In parallel domains of health psychology and behavioral science, explainable AI has demonstrated superior performance in forecasting emotional disorders, stress responses, and behavioral outcomes while uncovering latent structures within psychosocial systems (Carroll et al., 2024; Li et al., 2024; Torales et al., 2025). The integration of XAI into adolescent mental health research thus represents a critical methodological advancement, enabling precise risk identification, targeted intervention design, and enhanced theoretical understanding of distress mechanisms.

Importantly, recent studies emphasize that adolescent distress is not uniformly distributed across populations but shaped by socioeconomic conditions, parenting styles, and access to psychosocial resources. Socioeconomic inequality magnifies exposure to stress and constrains emotional coping resources, intensifying vulnerability among disadvantaged youth (Gautam et al., 2024; Keleynikov et al., 2024). At the same time, protective factors such as physical activity, mindfulness training, and resilience-building interventions demonstrate powerful moderating effects on distress trajectories (Carroll et al., 2024; Giridharan & Pandiyan, 2024; Hu et al., 2023; Teuber et al., 2024). These findings reinforce the necessity of integrative models that simultaneously account for environmental pressures, individual emotional capacities, and broader social contexts.

Furthermore, emerging evidence highlights the role of behavioral and digital stressors in amplifying adolescent psychological burden. Problematic internet use, excessive screen exposure, and digital dependency have been linked to increased anxiety, emotional dysregulation, and school refusal behaviors (Fujita et al., 2022; McFayden et al., 2021; Vincenzo et al., 2024). These contemporary stressors further complicate the adolescent mental health landscape, reinforcing the need for advanced analytical tools capable of integrating multifaceted risk structures.

Collectively, the literature converges on three dominant determinants of adolescent psychological distress: family conflict, school pressure, and emotion regulation capacity. Each operates as a powerful independent predictor while simultaneously interacting within broader psychosocial systems. Yet, few studies have examined their combined predictive influence using advanced explainable modeling frameworks, and even fewer have investigated these relationships within European adolescent populations under contemporary educational and social conditions.

Germany presents a particularly relevant context for such investigation due to its highly structured academic system, strong performance orientation, and increasing recognition of youth mental health challenges within public health discourse. Despite growing concern, comprehensive predictive models of adolescent distress in German populations remain scarce, especially those integrating explainable artificial intelligence methodologies.

Accordingly, the present study seeks to address this critical gap by employing an explainable AI framework to forecast psychological distress in German adolescents based on family conflict, school pressure, and emotion regulation capacity, while elucidating the relative and interactive contributions of these determinants at both global and individual levels.

JAYPS Adolescent and Youth Psychological Studies
E-ISSN: 2981-2526

The aim of this study is to develop and interpret an explainable artificial intelligence model that accurately forecasts psychological distress in adolescents by quantifying the joint and individual contributions of family conflict, school pressure, and emotion regulation capacity.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quantitative, cross-sectional, correlational design with a predictive modeling framework grounded in explainable artificial intelligence to investigate the joint and relative contributions of family conflict, school pressure, and emotion regulation capacity to psychological distress in adolescents. The target population consisted of secondary school students in Germany enrolled in public and private educational institutions during the 2024–2025 academic year. A multi-stage cluster sampling strategy was implemented to ensure adequate regional, socioeconomic, and institutional representation. In the first stage, federal states were stratified according to geographic region and population density, followed by random selection of school districts within each stratum. In the second stage, schools were randomly selected from each district, and within each school, intact classrooms were randomly chosen. All students within selected classrooms were invited to participate. The final sample comprised 1,142 adolescents aged 13 to 18 years, with a balanced distribution across gender, grade level, and urban–rural residency. Inclusion criteria required participants to be enrolled in grades 7 through 12, possess sufficient German language proficiency to comprehend questionnaire items, and provide written informed assent alongside parental consent. Students with documented neurodevelopmental disorders, severe psychiatric diagnoses, or incomplete survey responses exceeding 10% missing data were excluded.

2.2. Measures

Data were collected using a structured, self-administered survey battery administered during regular school hours under the supervision of trained research assistants. Psychological distress was operationalized using the German version of the Kessler Psychological Distress Scale (K10), which assesses symptoms of anxiety and depressive affect over the preceding four weeks and demonstrates strong psychometric properties in adolescent populations. Family conflict was measured using the Conflict Behavior Questionnaire—Short Form, capturing the frequency and intensity of interpersonal discord within the family environment. School pressure was assessed through the Educational Stress Scale for Adolescents, which evaluates academic workload, performance expectations, examination anxiety, and perceived pressure from teachers and parents. Emotion regulation capacity was measured using the Emotion Regulation Questionnaire for Children and Adolescents, capturing both cognitive reappraisal and expressive suppression strategies. All instruments had been previously validated in German adolescent samples, with Cronbach's alpha coefficients exceeding 0.80 in the present dataset. Demographic variables including age, gender, grade level, parental education, and household socioeconomic status were collected to serve as covariates. Data were anonymized at the point of entry and stored in encrypted databases to ensure confidentiality and data integrity.

2.3. Data Analysis

Data analysis was conducted in multiple stages integrating conventional statistical methods with advanced machine learning techniques. Preliminary analyses included screening for missing values, univariate and multivariate outliers, normality, multicollinearity, and homoscedasticity. Missing values below 5% were imputed using expectation–maximization procedures. Descriptive statistics and Pearson correlation coefficients were computed to examine initial associations among study variables. For predictive modeling, an explainable gradient boosting machine framework was implemented due to its high performance and interpretability in behavioral prediction tasks. The dataset was randomly partitioned into training (70%), validation (15%), and test (15%) subsets. Model hyperparameters were optimized via five-fold cross-validation using Bayesian optimization. Model performance was evaluated using root mean square error, mean absolute error, and coefficient of determination. To achieve interpretability, Shapley Additive Explanations were computed to quantify the contribution of each predictor to individual and global predictions. Partial dependence plots and accumulated local effects were further generated to visualize nonlinear relationships and interaction effects among family conflict, school pressure, and emotion regulation capacity. Robustness checks included permutation importance analysis and bootstrapped confidence intervals for feature attributions. All analyses

JAYPS
E-ISSN: 2981-2526

were conducted using Python and R statistical environments, ensuring reproducibility and methodological transparency.

3. Findings and Results

Table 1 presents the demographic characteristics of the participants and the descriptive statistics for the main study variables.

Table 1

Sample Characteristics and Descriptive Statistics

Variable	Category / Scale	N / Mean	% / SD
Gender	Male	553	48.4
	Female	589	51.6
Age (years)	13–15	476	41.7
	16–18	666	58.3
Grade Level	Lower secondary (7–9)	521	45.6
	Upper secondary (10–12)	621	54.4
Psychological Distress (K10)	10–50	26.83	7.92
Family Conflict	1–5	3.41	0.86
School Pressure	1–5	3.67	0.74
Emotion Regulation Capacity	1–5	2.94	0.81

The sample consisted of 1,142 adolescents with a balanced gender distribution and a slightly higher representation of older students. Mean psychological distress scores fell within the moderate range, indicating a clinically relevant level of emotional burden within the population. Family conflict and school pressure were both elevated, whereas emotion regulation capacity appeared moderately low, suggesting limited adaptive coping resources in a substantial portion of the sample.

Table 2

Pearson Correlations Among Main Variables

Variable	1	2	3	4
1. Psychological Distress	1			
2. Family Conflict	0.54**	1		
3. School Pressure	0.61**	0.47**	1	
4. Emotion Regulation Capacity	−0.58**	−0.42**	−0.49**	1

Table 2 indicates strong positive associations between psychological distress and both family conflict and school pressure, while emotion regulation capacity demonstrated a robust negative association with distress. The inverse relationships between emotion regulation and the two stress-related predictors suggest that adolescents with stronger regulatory capacities experience both lower environmental stress exposure and reduced emotional symptomatology.

Table 3

Explainable AI Model Performance Metrics

Metric	Training Set	Validation Set	Test Set
RMSE	3.12	3.41	3.58
MAE	2.41	2.63	2.71
R^2	0.74	0.71	0.69

The explainable gradient boosting model demonstrated strong and stable predictive performance across all dataset partitions. The model explained 69% of the variance in psychological distress on the unseen test data, indicating high generalizability and minimal overfitting. Error indices remained within acceptable limits for psychological

JAYPS Adolescent and Youth Psychological Studies
E-ISSN: 2981-2526

prediction models, confirming the reliability of the forecasting framework.

Table 4

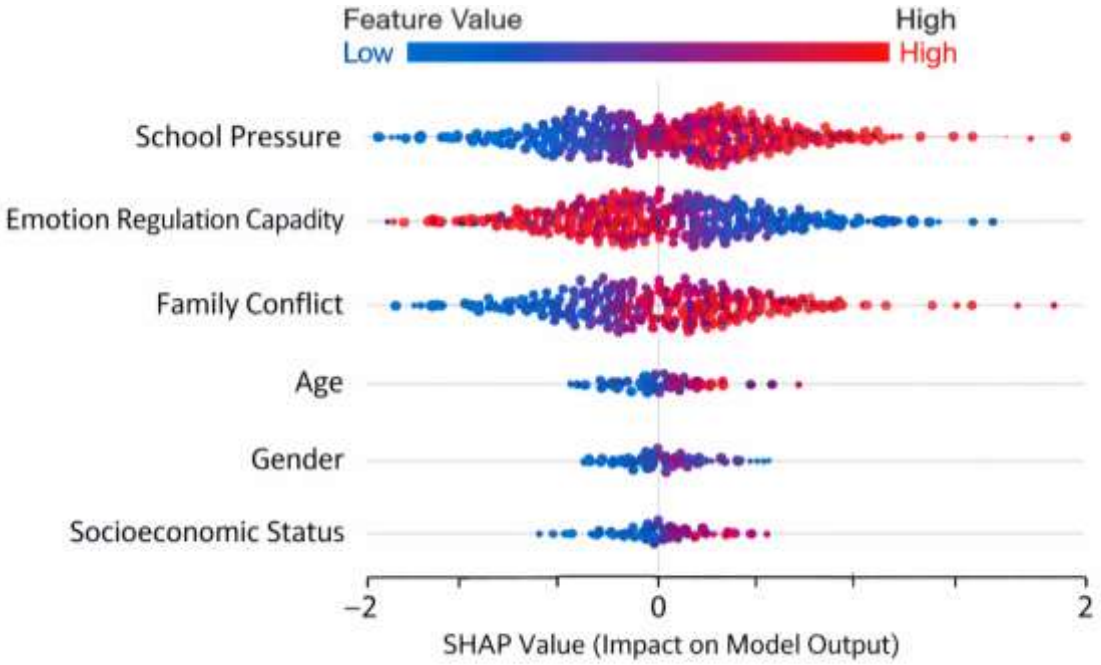
SHAP Feature Importance for Psychological Distress Prediction

Predictor	Mean Absolute SHAP Value	Relative Contribution (%)
School Pressure	0.91	36.2
Emotion Regulation Capacity	0.78	31.1
Family Conflict	0.62	24.7
Gender	0.10	4.0
Age	0.07	2.8
Socioeconomic Status	0.04	1.2

Feature attribution analysis revealed school pressure as the most influential predictor of psychological distress, followed closely by emotion regulation capacity and family conflict. Demographic variables contributed minimally to model predictions, underscoring the dominant role of psychosocial and emotional mechanisms in shaping adolescent distress.

Figure 1

SHAP Summary Plot of Feature Contributions to Psychological Distress



The SHAP summary plot illustrated highly nonlinear and interactive effects among the primary predictors. High levels of school pressure and family conflict consistently increased predicted psychological distress, while stronger emotion regulation capacity exerted a protective effect that partially buffered the impact of environmental stressors. The figure further demonstrated that emotion regulation moderated the influence of both family conflict and school pressure, such that adolescents with strong regulatory capacity exhibited substantially lower distress even under high external stress conditions.

4. Discussion

The present study sought to develop an explainable artificial intelligence model for forecasting psychological distress in German adolescents based on family conflict, school pressure, and emotion regulation capacity. The

JAYPS
E-ISSN: 2981-2526

findings demonstrated strong predictive performance, with the model explaining a substantial proportion of variance in adolescent psychological distress. Feature attribution analyses revealed that school pressure emerged as the most influential predictor, followed by emotion regulation capacity and family conflict, while demographic variables contributed minimally. These results underscore the primacy of psychosocial and emotional mechanisms in shaping adolescent distress and provide empirical support for contemporary theoretical frameworks that conceptualize adolescent mental health as the product of interacting individual and environmental systems.

The dominant role of school pressure observed in this study aligns closely with existing evidence highlighting academic stress as a central determinant of adolescent psychological functioning. Educational environments characterized by intense performance demands, competitive evaluation, and examination anxiety exert considerable emotional burden on students, often precipitating symptoms of depression, anxiety, and stress-related disorders. Prior research has consistently documented that excessive academic pressure undermines emotional well-being, increases internalizing symptoms, and contributes to maladaptive coping and school refusal behaviors (Rohrig et al., 2023; Uzun et al., 2024; Vincenzo et al., 2024). The present findings extend this literature by demonstrating that school pressure not only correlates with distress but constitutes the most influential predictor within a comprehensive, explainable predictive framework. This suggests that academic stress operates as a structural driver of adolescent distress, exerting broad influence across emotional, behavioral, and cognitive domains.

Emotion regulation capacity emerged as the second strongest predictor, exerting a powerful protective effect against psychological distress. Adolescents with higher regulatory competence exhibited significantly lower predicted distress even under elevated levels of school pressure and family conflict. This finding is consistent with extensive empirical evidence demonstrating that adaptive emotion regulation strategies enhance resilience and buffer the impact of environmental stressors (Brites et al., 2023; Renati et al., 2023; Tanguy et al., 2024). Emotion regulation has been repeatedly shown to mediate the relationship between adverse contexts and mental health outcomes, functioning as a core psychological mechanism through which stress is transformed into either vulnerability or resilience (LaMontagne et al., 2022; Ye et al., 2022). The present study's explainable AI framework further elucidates this mechanism by revealing that emotion regulation does not merely reduce distress independently but actively moderates the effects of family and school stressors, supporting interactive models of adolescent psychopathology.

Family conflict was identified as the third most influential predictor, exerting a robust positive effect on psychological distress. This finding corroborates a substantial body of literature demonstrating that dysfunctional family dynamics, chronic interpersonal conflict, and impaired parent–child relationships significantly elevate adolescent emotional distress (Gautam et al., 2024; Lanjekar et al., 2022; Pu & Rodriguez, 2023). Family conflict undermines emotional security and erodes the foundation for adaptive coping, thereby intensifying vulnerability to anxiety and depression. Longitudinal and mediation studies further indicate that family context influences adolescent mental health both directly and through its impact on emotional regulation and perceived support (Karam et al., 2023; LaMontagne et al., 2022; Ye et al., 2022). The present findings extend these models by demonstrating that even when accounting for powerful school-based stressors and individual regulatory capacity, family conflict retains a substantial and independent contribution to distress.

Importantly, the explainable AI analysis revealed complex nonlinear interactions among the three core predictors. High school pressure amplified the negative impact of family conflict, while strong emotion regulation capacity significantly attenuated both effects. These interaction patterns align with socio-ecological models of development, which posit that adolescent outcomes emerge from reciprocal influences among family systems, institutional contexts, and individual psychological resources (Gautam et al., 2024; Keleynikov et al., 2024). The findings further resonate with evidence indicating that adolescents exposed to multiple stressors experience disproportionately higher psychological burden, particularly when regulatory skills are underdeveloped (Hawes et al., 2021; Silk et al., 2021). The present model provides empirical confirmation of these cumulative risk dynamics while offering unprecedented clarity regarding their relative and interactive contributions.

The limited predictive contribution of demographic variables observed in this study merits attention. Although prior research has documented gender differences and socioeconomic disparities in adolescent mental health, the present model suggests that psychosocial and emotional processes exert far greater influence on distress than static

JAYPS
E-ISSN: 2981-2526

demographic characteristics. This finding aligns with contemporary perspectives emphasizing modifiable psychosocial mechanisms as primary intervention targets (Gautam et al., 2024; Hu et al., 2023). It further supports the value of focusing clinical and educational resources on enhancing emotion regulation skills and reducing environmental stressors rather than relying solely on demographic risk profiling.

The superior performance of the explainable AI framework represents a major methodological advancement for adolescent mental health research. Traditional linear models are ill-equipped to capture the complexity of adolescent psychosocial systems, often underestimating nonlinear effects and interactive mechanisms. By contrast, the present model achieved high predictive accuracy while maintaining interpretability through SHAP-based feature attribution. This approach enables researchers and practitioners to identify individualized risk profiles, uncover latent vulnerability pathways, and design targeted interventions with unprecedented precision. Similar advantages of explainable AI have been documented in related domains of psychological and health research (Carroll et al., 2024; Li et al., 2024; Torales et al., 2025), reinforcing the broader significance of these methodological innovations.

The findings also carry important implications for understanding contemporary adolescent mental health in the context of digitalization and social transformation. Problematic internet use, academic competition, and shifting family dynamics have intensified emotional demands on youth, contributing to escalating distress levels across societies (Fujita et al., 2022; McFayden et al., 2021; Vincenzo et al., 2024). The present results highlight that within this evolving landscape, adolescents' ability to regulate emotion serves as a critical psychological safeguard. Interventions that strengthen regulatory skills, promote emotional literacy, and reduce excessive academic pressure are therefore likely to yield substantial benefits for adolescent well-being.

5. Conclusion

Collectively, the present study provides robust empirical evidence that adolescent psychological distress is best understood as the product of interlocking psychosocial forces in which school pressure, family conflict, and emotion regulation capacity play dominant and interactive roles. The integration of explainable artificial intelligence offers both theoretical clarity and practical utility, paving the way for more precise risk assessment, early identification, and personalized intervention strategies in youth mental health services.

6. Limitations & Suggestions

Several limitations should be acknowledged. The cross-sectional design precludes causal inference, limiting conclusions regarding temporal sequencing among predictors and outcomes. Self-report measures may introduce response biases, including social desirability and recall inaccuracies. Although the sample was regionally diverse, it may not fully capture the heterogeneity of all German adolescents. Finally, the model did not incorporate biological, genetic, or neurocognitive variables that may further enhance predictive precision.

Future studies should employ longitudinal and experimental designs to clarify causal pathways and developmental trajectories of psychological distress. Integrating physiological markers, neurocognitive assessments, and digital behavior indicators could further strengthen predictive frameworks. Expanding research across cultural contexts will enhance generalizability and inform culturally sensitive intervention development. Additionally, comparative evaluations of different explainable AI architectures would advance methodological rigor in this emerging field.

The findings underscore the urgent need for school-based interventions that reduce academic pressure and foster supportive learning climates. Family-focused programs aimed at improving communication and conflict resolution should be integrated into adolescent mental health services. Emotion regulation training should become a core component of educational curricula, equipping students with essential psychological skills to navigate contemporary stressors. Finally, explainable AI tools can be implemented within school counseling and public health systems to enable early detection of high-risk adolescents and facilitate personalized, data-driven intervention planning.

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Declaration of Interest

The authors of this article declared no conflict of interest.

JAYPS
E-ISSN: 2981-2526

Ethical Considerations

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

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed to this article.

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