

A Machine Learning–Driven Framework for Modeling and Forecasting Suicide Mortality in Asia: The Role of Multidimensional Socio-Economic Determinants

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Abstract

Suicide is regarded as a public health emergency, which is believed to be mediated by important socio-economic factors that differ between geographical areas. In the current study, the association of 22 socio-economic indicators with total suicide rates was examined, using data obtained from the World Data Bank across six Asian countries. Advanced machine learning techniques such as XGBoost, Random Forest, AdaBoost, Gradient Boosting, and LightGBM were applied. Among these, XGBoost was found to perform best after extensive hyperparameter optimization, with an adjusted R^2 of 0.718 and RMSE of 1.536 on the training data, and an adjusted R^2 of 0.773 and RMSE of 3.857 on the test data. For interpretation, Partial Dependence Plots (PDPs) of the XGBoost model were plotted, providing the marginal effects of certain individual factors on the response of interest – suicide rates. This work is intended to contribute to the existing body of knowledge on the socio-economic determinants of suicide that can be used to inform evidence-based interventions.

Keywords

Suicide Risk Factors, Data Modeling, Cross-Regional Analysis, Socioeconomic Indicators, Risk Assessment.

1. Introduction

According to the WHO, approximately 1 million people are reported to die each year from suicide (Dwivedi 2023). Suicide is considered one of the hardest problems to deal with due to the involvement of multiple socio-cultural and psychological characteristics. However, while the suicide rates are found to vary in terms of countries and regions, the tools to address the issue are considered to be keyed to the aspects mentioned above. This is why, by defining the socio-economic and cultural determinants, impressive results in terms of the reduction of suicide rates can be achieved (Küey 2022). This study is aimed at identifying and evaluating the most significant socio-economic and cultural factors influencing the total suicide rate. Drawing on the extensive data available from the World Data Bank, a range of socio-economic variables concerning the Asian countries in question is examined (World Bank 2023). These include how high the levels of unemployment are, income inequity, how politically stable a country is, and whether preventative measures are supported, in terms of whether suicide is taboo culturally. Further, the multicollinearity between the independent variables is aimed to be distinguished. Policymakers and healthcare providers are encouraged to take these factors into account, especially given that this phenomenon is found to vary by region.

1.1 Objectives

1) To implement machine learnings (such as XGBoost, LightGBM and Random Forest) to model suicide rates in six chosen Asian nations using socioeconomic and cultural factors.

- 2) To use feature importance analysis based on models to determine and rank the most important elements influencing suicide rates.
- 3) To use partial dependency plots (PDPs) to graphically depict the relationship between important socioeconomic factors and suicide rates.

2. Literature Review

In order to understand the complex socioeconomic and cultural elements which impact suicide rates globally, a thorough literature analysis is essential. Critical variables may be more easily identified thanks to this technique, which also highlights regional differences and trends. We have offered a more thorough study by taking into consideration factors that others did not completely account for. Generosity is one of them. Many researchers have examined the relationship between generosity and suicide rate (Minkov et al. 2022; Zadavec Šedivy et al. 2017; Harder et al. 2024). The researcher found some patterns with generosity. Suicide rates were shown to be significantly predicted by cultural factors such as inadequate socializing, based on the analysis of data from 53 countries in Central and Northeast Europe and Northeast Asia from 2015 to 2016 (Minkov et al. 2022). Minkov et al. (2022) also found that persons who engage in volunteering and care-providing activities have a lower likelihood of developing suicidal tendencies. Zadavec Šedivy et al. (2017) demonstrated that kindness and support from others can improve an individual's well-being and mental health. Harder et al. (2024) used logistic regression on United States data in 2019 and indicated that creating a supportive atmosphere might be beneficial in reducing suicidality among people, regardless of their demographic characteristics. It is very obvious that economic stability is closely related to generosity (Meer and Priday 2020). An individual will be more generous if the person has economic stability in life.

Helliwell (2007) investigated the link between suicide rates and life satisfaction in Scandinavian nations, however the precise time frame of the investigation was not stated. Economic security gives people a feeling of stability and predictability in their financial circumstances, therefore enhancing their overall life happiness (Vandoros and Kawachi 2021). Higher life satisfaction eventually decreases the suicide rate (Vandoros and Kawachi 2021). Han and Gao (2020) found that welfare systems could directly affect the quality of life. In that case, the problems with suicide may also be expected to decrease. One should note that strong social policies and support systems help to buffer the effects of a lower life satisfaction level, which can decrease the direct impacts on suicide rates (Han and Gao 2020). Crime rate can influence suicide rate. Monson et al. (2023) investigated the risk factors associated with clinical and genetic trauma that contribute to suicide fatalities in the United States. Using a dataset of 62 case files and qualitative analysis based on General Strain Theory, research investigated that crime can lead to an economic burden which can contribute to feelings of despair. Which increases the risk of suicide (Stack and Wasserman 2007). However, the connection between crime rates, social marginalization, and increased vulnerability to suicide is complicated and diverse (Dean 2023). The interrelation between the perception of corruption and the suicide rate and was also analyzed in many papers (Lorant et al. 2018; Zhang 2022). The research of Zhang (2022) which was conducted in China, emphasized that there is a positive association between the perception of government corruption and the presence of depression symptoms among persons. Corruption has the potential to worsen existing inequalities, hence resulting in elevated suicide rates among vulnerable groups (Lorant et al. 2018). Healthy life expectancy at birth is also a significant factor in the suicide rate which is highly researched by researchers (Nishi 2023). Life expectancy is determined by the people's mental health. Poor mental health leads to dangerous and unhealthy behavior which may affect the life expectancy of a person. People with mental health problems such as depression and PTSD can trigger suicidal thoughts (Nishi 2023). The unemployment rate can give different relations in different continents due to various reasons. Besharov and Call (2023) showed that compared to many Asian nations, social safety nets in Europe are typically more extensive and well-funded. Safety-net initiatives can help reduce unemployment by offering financial support, encouraging job search behavior, and fostering skill development (Besharov and Call 2023). Taking sociocultural aspects into account, another study used a systematic mixed study review to investigate how Asian American college students seek mental health care (Nguyen, Kim, and Aronowitz 2024). South Asian countries have a significant mental health treatment gap because of a lack of professionals, insufficient funding, and the pervasive stigma attached to mental illnesses (Grover 2023). It is commonly acknowledged that depression is a major risk factor for suicide and that it is one of the main reasons (Arnone et al. 2024; Saltman, Yeh, and Liu 2022). Studies revealed that people with depressive disorders are significantly more inclined to have suicidal thoughts and attempts. How these socioeconomic and cultural factors especially affect suicide rates in these populations may not be adequately covered in the paper (Arnone et al. 2024). Research examined the effects of diverse cultural backgrounds and social norms on health outcomes-which could extend to understanding suicide rates-was conspicuously lacking (Saltman, Yeh, and Liu 2022). According to the research of Lamichhane (2023), cultural norms and beliefs frequently play a role in the

stigmatization of mental health concerns, which makes people reluctant to seek help and have open conversations about mental health. The study highlighted the need for more research in this field by concentrating on mental health literacy and stigma in South Asian nations. Freedom has been found to have an impact on suicidal thoughts by multiple research studies (Akaliyski 2023). Many Asian nations have authoritarian political systems that restrict civil liberties and political involvement, which stifles personal freedoms (Akaliyski 2023).

Although there is a large amount of research on the specific socioeconomic and cultural factors that affect suicide rates, such as life expectancy, generosity, corruption, unemployment, and mental health, previous studies have tried to concentrate on specific geographic areas, use conventional statistical techniques, or look at these factors separately. Integrated, multi-country analyses that use sophisticated machine learning models to consider complex relationships and non-linear linkages are lacking in the Asian context. Few studies have also integrated other factors (such as freedom, health, corruption, and generosity) into a single framework.

3. Methods

3.1 Data Collection

The dataset that was used in this study was retrieved from the World Data Bank Open Data repository and it covers the time series between 2000 and 2021 (World Bank 2023). It includes the review period and provides an inclusive pretext of annual socio-economic indicators of six Asian countries. The proposed analysis will be focused on India, Pakistan, China, Japan, Israel and Kazakhstan. The dependent variable will be considered as total suicide rate per 100,000 population, and quantifying the number of socio-economic factors that influence the total suicide rate by a substantial margin, will be set as the major goal.

Based on data from the World Data Bank, the predictors of suicide rates are shown in Figure 1, divided into five domains: economic, mental health and crime, governance, social well-being, and health. The response variable is represented by the overall suicide rate per 100,000 people.

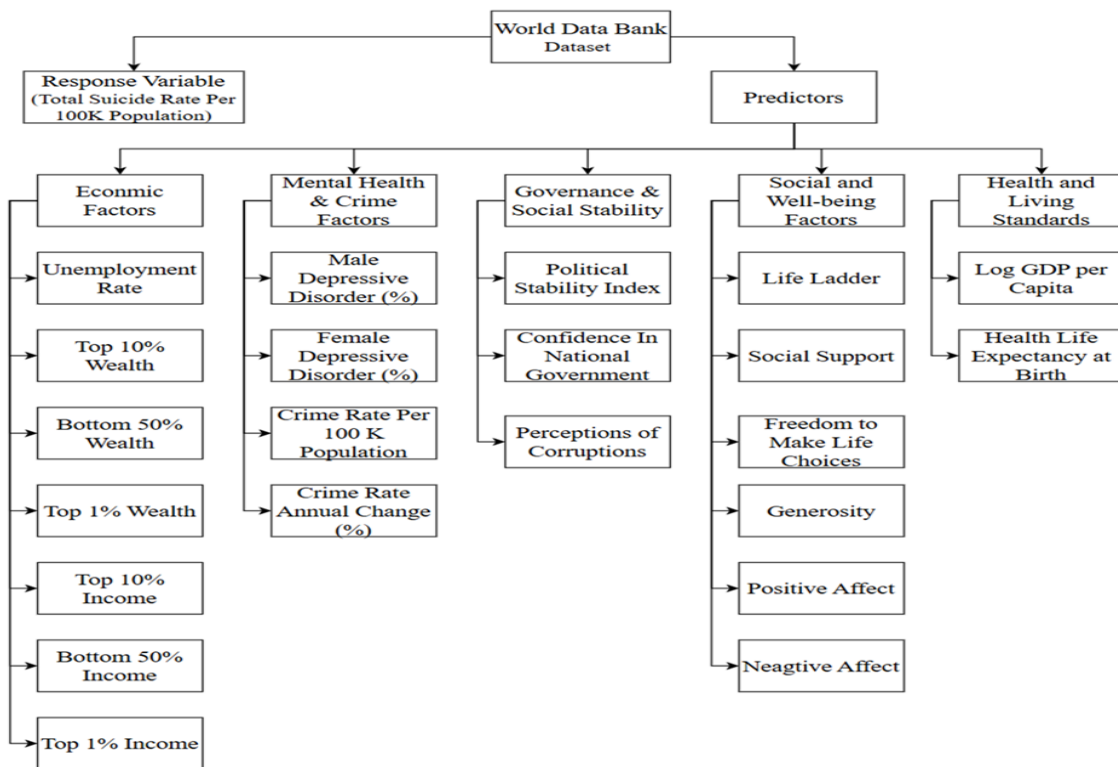


Figure 1. Response Variables and Predictors

3.2 Data Preprocessing

In the pre-processing step, examples in the dataset that were detected as missing completely at random (MCAR) were filled by estimates obtained with Matrix Factorization. The procedure is convenient since it has the effect of extracting latent structures and maintaining relationships among the variables, hence imputing factors with a higher precision compared to simpler methods. Standardization of the variables to zero mean and unit variance was then performed, which makes the features comparable, and allows the model to be more stable alongside improving interpretability. In this Figure 2, the methodological approaches are included: data collection and preprocessing, model training with repeated K-fold cross-validation, hyperparameter tuning with Bayesian optimization, model evaluation, and interpretation using PDP and feature importance plots.

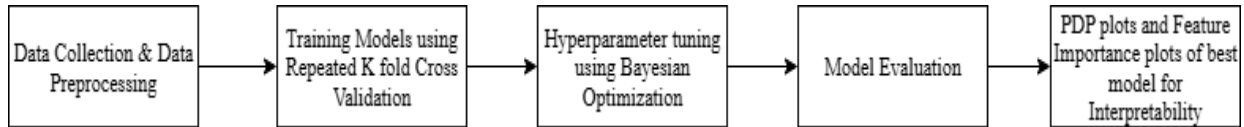


Figure 2. Workflow of the Analytical Framework

3.3 Exploratory Data Analysis

Under the exploratory stage, the Spearman correlation matrix was used to test monotonic correlations between the total suicide rate per 100,000 and a set of socio-economic indicators. Spearman correlation was selected because of its robustness to non-linear and non-parametric directions. Complementary testing on descriptive measures-mean, median, standard deviation, and range-was done to create an overview of how the Total Suicide Rate is distributed per territory and per time, and to give some first indications to be used in the following modeling. The mean, median, standard deviation, and range of rates are among the metrics that are highlighted in Table 1, which is used to display descriptive data of the overall suicide rates per 100,000 population for six different nations.

Table 1: Descriptive Statistics of Total Suicide Rate Per 100K

Country	Mean	Median	Standard Dev.	Min	Max
China	10.49	10.45	2.04	8.1	14.3
India	14.24	14.55	1.55	12.0	17.0
Israel	5.69	5.45	0.63	4.5	6.8
Japan	21.29	23.3	3.74	14.52	25.6
Kazakhstan	29.41	29.3	8.51	16.0	39.7
Pakistan	8.97	8.97	0.14	8.7	9.2

Figure 3 shows the Spearman correlation coefficients between different socioeconomic and psychological aspects and the suicide rates per 100,000 people in six countries: Kazakhstan, Israel, Pakistan, Japan, China, and India.

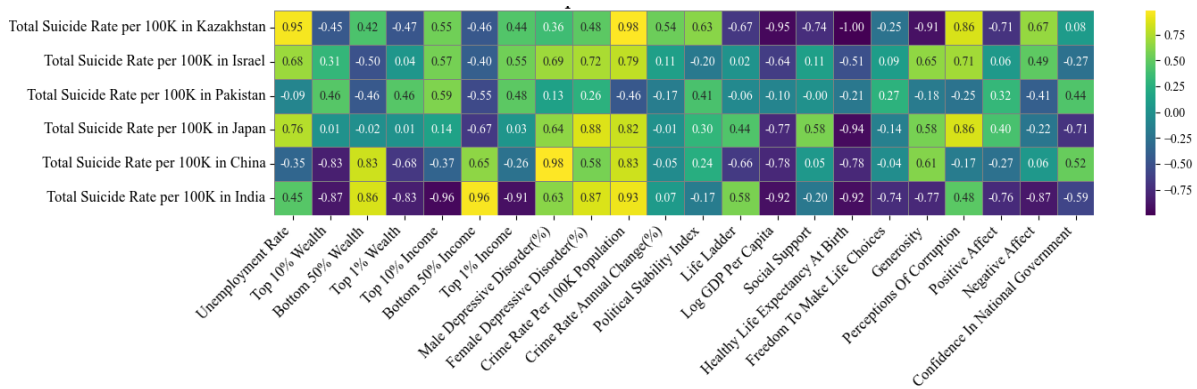


Figure 3. Spearman Correlation Matrix

3.4 Model Selection and Development

Five tree-based ensemble models, namely, Random Forest, LightGBM, XGBoost, Gradient Boosting Regressor, and AdaBoost, were used to model the total suicide rate per 100,000 of the population. Out of the models to be chosen motivated by their ability to account for non-linear relationships and multicollinearity, they were further characterized by their interpretability in terms of feature importance and partial dependence plots.

In order to guarantee resilience and generalizability, 5 splits and 10 repeats of Repeated K-Fold Cross-Validation were carried out. Hyperparameters were fine-tuned over model hyperparameters using Bayesian Optimization that was shown to outperform grid search in terms of performance without incurring large amounts of computation.

3.5 Model Evaluation

Model performance was assessed using R^2 , Adjusted R^2 and RMSE on both training and testing datasets. Among these, Adjusted R^2 was given the most importance, as it adjusts for the number of predictors and better reflects model generalizability and the ability to capture true variance without overfitting.

In Table 2, Random Forest model was observed to have achieved the highest Adjusted R^2 on the test set (0.823), but its low training Adjusted R^2 (0.640) was taken to indicate possible underfitting or inconsistency. In contrast, XGBoost was shown to exhibit more stable and balanced performance, with a training Adjusted R^2 of 0.718 and a test R^2 of 0.774. Due to its consistency across datasets, XGBoost was selected as the final model for identifying the most influential socio-economic factors affecting the suicide rate.

Table 2: Performance metrics (RMSE, R^2 , and Adjusted R^2) for different models

Models	Train RMSE	Train R^2	Train Adj. R^2	Test RMSE	Test R^2	Test Adj. R^2
Random Forest	1.813	0.953	0.64	3.41	0.823	0.823
LightGBM	1.978	0.938	0.526	3.894	0.77	0.769
XGBoost	1.536	0.964	0.718	3.857	0.774	0.773
Gradient Boosting Tree	1.752	0.95	0.61	4.042	0.752	0.751
Adaboost	1.982	0.939	0.525	3.453	0.819	0.818

3.6 Feature Importance Plot and Interpretation

The F-score-based feature importance from the best-performing XGBoost model was used to identify key socio-economic factors. The F-score reflects how often a feature is used to split data in the trees-higher scores indicate greater influence on the model's predictions. This analysis highlights the most impactful indicators related to the Total Suicide Rate, enhancing interpretability and guiding further investigation.

The bar chart in Figure 4 ranks the predictors of suicide rates according to feature relevance based on the F-score for XGBoost model. The correlation analysis's findings are supported by the findings that the top predictors are the following: the unemployment rate, the crime rate per 100,000 people, and the wealth of the bottom 50%. Social measures like Political Stability and Healthy Life Expectancy, as well as psychological health indicators like Male Depressive Disorder (%), are considered important.

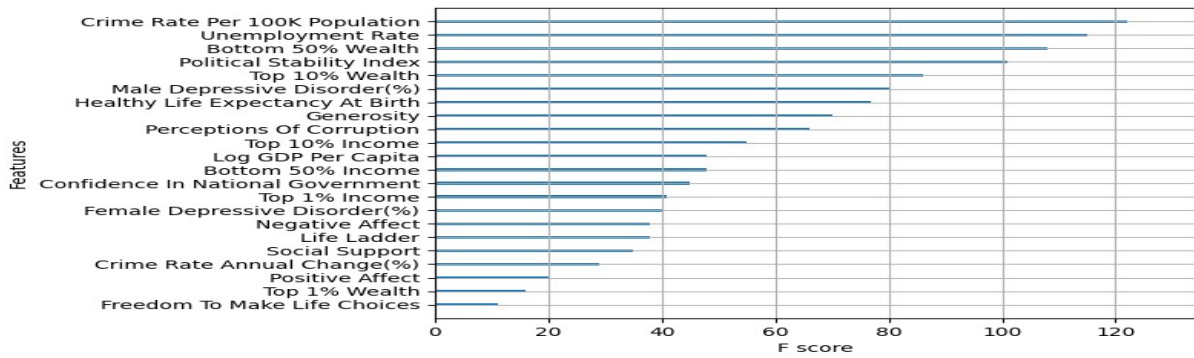


Figure 4. Feature Importance for XGBoost

3.7 Tools & Libraries Used

All analysis steps have been conducted in Python with a set of powerful libraries in data-science. Data management and analysis were performed using Pandas, and preprocessing, model training and evaluation were carried out with Scikit-learn. The performance of the proposed approach using XGBoost model was evaluated with the help of the XGBoost library, and Optuna was used to realize effective Bayesian hyperparametric optimization.

5. Results and Discussion

Generosity is expressed through various behaviors such as financial giving, volunteering, and helping strangers. In Figure 3, a negative association was observed between generosity and suicide rates in Asia. Countries such as Kazakhstan (Spearman correlation: -0.91), India (-0.77), and Pakistan (-0.18) were found to have negative correlations with suicide rates. Stagnant correlations were reported for other countries, resulting in an overall negative association between generosity and suicide rates across the region. In Figure 5, a gentle decline was shown by the Partial Dependence Plot (PDP) as generosity increased, suggesting that a protective effect might be present. In collectivist Asian societies, where community and family support are emphasized, stronger social ties are reflected by higher generosity and are believed to act as buffers against suicide. A study conducted in the US in 2019 by Wyman et al. (2019) demonstrated that community structures fostering social integration, support, and strong connections were associated with a decreased occurrence of suicide attempts (Donovan et al., 2024).

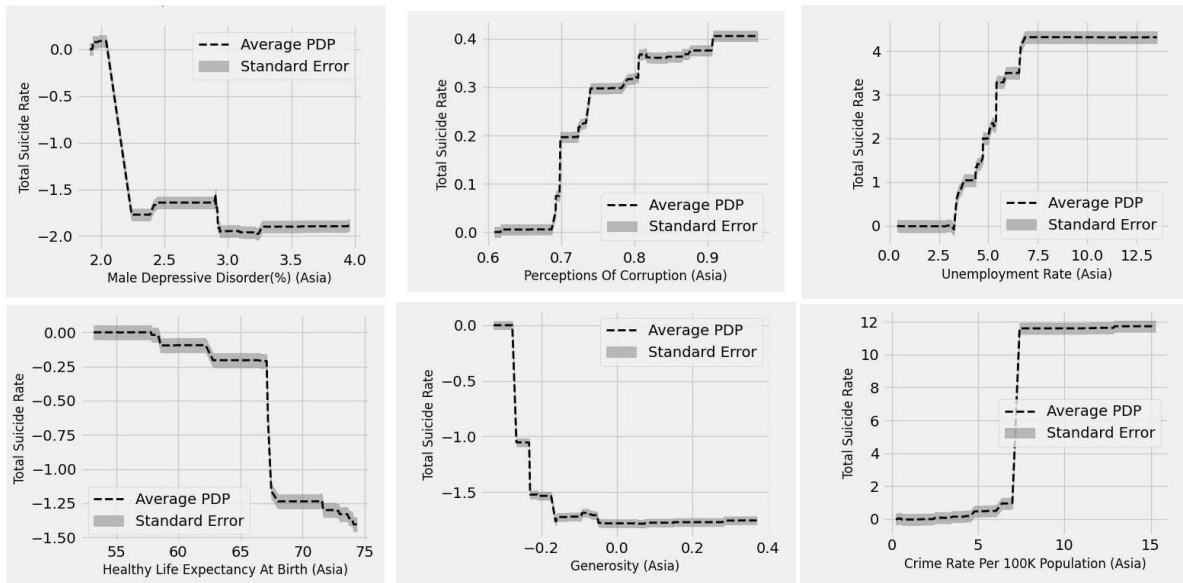


Figure 5. PDP plots

The perception of corruption is defined as the way in which the degree of corruption within a country is viewed by individuals both domestically and globally (Saha et al., 2023). In Figure 3, a positive association was shown between this factor and the suicide rate in Asia. Positive correlations with suicide rates were reported in most countries, including India (Spearman correlation: 0.47), Israel (0.70), and Japan (0.86), while some countries were found to exhibit negative correlations. A slight upward trend was shown by the Partial Dependence Plot (PDP) in Figure 5, indicating that lower perceived corruption (i.e., a higher CPI score) may be associated with slightly higher suicide rates. It has been suggested that countries with low levels of corruption may also be characterized by high levels of competition and urbanization, where societal expectations and isolation could contribute to increased vulnerability to suicide. It was investigated by Farhan, Saleem, and Ahmed (2024) that perceiving corruption as widespread may lead to a significant loss of trust in governmental institutions. The feeling of despair was identified as a key factor potentially leading to mental health issues, including suicidal ideation (Farhan, Saleem, and Ahmed, 2024).

Healthy life expectancy is calculated at birth and is considered a reflection of the overall quality of life and standard of living experienced by individuals throughout their lives (Islam et al., 2023). In Figure 3, a negative association was shown between healthy life expectancy and suicide rates in Asia. Negative correlations were reported for countries such as China (Spearman correlation: -0.77), India (-0.92), Israel (-0.51), and Japan (-0.93). In Figure 5, a clear decline was displayed by the Partial Dependence Plot (PDP), suggesting that improved overall health may be linked to lower suicide rates. In Asia, higher life expectancy is often associated with stronger healthcare systems and increased mental health awareness, which are believed to contribute to reduced suicide risks over time. It was demonstrated by Piatkowska, Raffalovich, and Messner (2016) that greater life expectancy and higher GDP per capita are associated with decreased suicide rates. Better healthcare systems are frequently observed in countries with longer life expectancies, and increased funding for mental health has been linked to lower suicide rates (Shah and Bhat, 2009). The unemployment rate is measured by the percentage of the labor force that is actively seeking employment but does not currently hold a job. In Figure 3, a positive association was observed between the unemployment rate and suicide rates in Asia. Positive correlations were reported in countries such as Japan (Spearman correlation: 0.76), India (0.45), and Kazakhstan (0.95). The plots in Figure 5 revealed an initially flat curve, followed by a sharp increase after the 5–6% unemployment mark. It was indicated by Fountoulakis et al. (2014) that suicide rates tend to decline as unemployment increases. However, a significantly positive connection between unemployment in Asia and suicide rates was reported by Yamasaki, Sakai, and Shirakawa (2005). When social pressures and expectations are combined with the psychological distress caused by job loss, individuals without employment may be placed in a vulnerable position, increasing their risk of suicide (Seksenbayev et al., 2022).

Depression is recognized as a medical condition that can be treated, rather than a personal weakness or character flaw. In Figure 3, a positive correlation was identified between male depressive disorder and suicide rates in Asia. Countries such as Japan (Spearman correlation: 0.64), India (0.63), and China (0.98) were found to have a positive connection with suicide rates in terms of male depressive disorder. One of the steepest rises in the PDPs was shown for male depressive disorder in Figure 5, indicating a strong and direct link to suicide. In many Asian cultures, vulnerability is stigmatized among men, and untreated depression is often allowed to escalate, contributing to the marked increase in suicide rates as the prevalence of depressive disorder rises. Low levels of investment in mental health have been noted across Asia, resulting in inadequate mental health services to meet the growing demand (Talwar, Appleton, and Billings, 2024). A slight upward trend was observed in Figure 5, suggesting that lower perceived corruption (higher CPI score) may be associated with slightly higher suicide rates. It has been proposed that in Asia, countries with lower levels of corruption may also be more competitive and urbanized, where heightened societal expectations and social isolation can be counterintuitively linked to increased vulnerability to suicide.

6. Conclusion

Suicide rates and the influence of socioeconomic and cultural factors are thought to be complicated phenomena. Suicide rates in a number of Asian countries have been examined in connection to key factors using data from the World Data Bank. Since it has been established that sociocultural and economic factors play a critical role in preventing suicide, these findings are considered significant by policymakers. These characteristics should be taken into consideration when developing prevention efforts in order to address underlying causes and enhance access to mental health treatments. This study has been recognized to have certain shortcomings. With a small sample size, generalization may be affected. Even while machine learning models like Random Forest and XGBoost demonstrated high performance, it has been found to be challenging to isolate the effects of specific parameters due to their complexity. Additionally, some significant elements might have been left out of the analysis. This work's primary

innovation lies in the integrated method that was used, not in the factors examined. Although these elements have been examined previously, they have not been examined as a whole. The usage of PDPs and machine learning has been shown to offer a fresh analytical and visual viewpoint on their relationship to suicide rates.

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Biographies

Fahimul Haque is an undergraduate final year student of Industrial and Production Engineering with expertise in statistical learning, machine learning, optimization, and computational intelligence. His research includes nonlinear and explainable machine learning models for suicide mortality prediction using high-dimensional socio-economic data, Bayesian self-supervised MLPs for initialization-free constrained optimization, and multi-agent reinforcement learning (PPO) for evolutionary game equilibrium recovery. In manufacturing systems, he develops hybrid RSM–ML frameworks, symbolic regression, and ensemble models for surface roughness and flank wear prediction in advanced drilling processes. His work emphasizes model interpretability, generalization, and decision-oriented predictive analytics.

Mahamudul Hassan Siddique is an undergraduate final year student of Department of Industrial and Production Engineering at BUET. He is studying the multi-tier supply chain optimization under the reinforcement learning in his thesis. His areas of research concern machine learning, deep learning, natural language processing, large language models, operations research, and optimization. He integrates the use of statistics and the AI techniques to come up with data-driven answers to complicated industrial challenges. His research is based on the interplay of conventional optimization with state-of-the-art computational models in aid of intelligent decision making.

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