Internet Use, Socioeconomic Indicators, and Suicide Mortality: An Ecological Analysis

Utilisation d'Internet, indicateurs socioéconomiques et mortalité par suicide : analyse écologique

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Abstract | Résumé

This study examined the associations between internet use, socioeconomic factors, and suicide mortality from 2015 to 2023 using World Bank data. The objective was to evaluate how technological access correlates with social and economic development indicators in relation to population-level mental health outcomes. The assessment analyzed Country-level data on internet penetration, GDP per capita, literacy, suicide mortality rates, life expectancy, school enrollment, unemployment, electricity access, and population growth. Correlation analyses, descriptive statistics, and global mapping summarized patterns, while hierarchical linear regression models adjusted for demographic and socioeconomic factors in stages. Results showed significant variation in internet use (2.2–100%) and suicide mortality (0.63–29.53 per 100,000). High-income countries had higher internet penetration (≅ 85%) and elevated suicide rates (≅ 9–11 per 100,000) compared to low-income countries (≅ 11% internet use; ≅ 6.5 per 100,000 suicide). Internet use was strongly correlated with GDP (r ≅ 0.70), literacy (r ≅ 0.60), and life expectancy (r ≅ 0.65). In regression models, internet use showed a weak positive association in unadjusted analyses that reversed to a negative association after accounting for socioeconomic factors (β = -0.30, 95% CI: -0.50, -0.10). Life expectancy and school enrollment were also associated with suicide mortality.

These findings indicate that the ecological, cross-sectional association between access to the internet and deaths from suicide is influenced by national socioeconomic circumstances. While more developed countries that had higher levels of internet access were more likely to have lower levels of suicide, the nature of the cross-sectional data and ecological design does not allow causal inference. These results are also important because they show the need to take national socioeconomic status into account when studying relationships between digital technology and the population's health status.

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Cette étude a examiné les associations entre l'utilisation d'Internet, les facteurs socioéconomiques et la mortalité par suicide de 2015 à 2023, à partir des données de la Banque mondiale. L'objectif était d'évaluer comment l'accès aux technologies est lié aux indicateurs de développement social et économique, en lien avec les résultats de santé mentale à l'échelle des populations. L'analyse portait sur des données nationales concernant la pénétration d'Internet, le PIB par habitant, l'alphabétisation, les taux de mortalité par suicide, l'espérance de vie, la scolarisation, le chômage, l'accès à l'électricité et la croissance démographique. Des analyses de corrélation, des statistiques descriptives et des cartes mondiales ont permis de résumer les tendances observées, tandis que des modèles de régression linéaire hiérarchique ont ajusté progressivement les résultats pour des facteurs démographiques et socioéconomiques. Les résultats ont montré une variation importante de l'utilisation d'Internet (2,2 à 100 %) et de la mortalité par suicide (0,63 à 29,53 décès par 100 000 habitants). Les pays à revenu élevé présentaient une pénétration d'Internet plus élevée (environ 85 %) et des taux de suicide plus élevés (environ 9 à 11 décès par 100 000 habitants) que les pays à faible revenu (environ 11 % d'utilisation d'Internet; environ 6,5 décès par 100 000 habitants). L'utilisation d'Internet était fortement corrélée avec le PIB (r ≅ 0,70), l'alphabétisation (r ≅ 0,60) et l'espérance de vie (r ≅ 0,65). Dans les modèles de régression, l'utilisation d'Internet montrait une faible association positive dans les analyses non ajustées, mais cette association devenait négative après la prise en compte des facteurs socioéconomiques (β = -0,30; IC à 95 % : -0,50 à -0,10). L'espérance de vie et la scolarisation étaient aussi associées à la mortalité par suicide.

Ces résultats indiquent que l'association écologique et transversale entre l'accès à Internet et les décès par suicide est influencée par les conditions socioéconomiques nationales. Même si les pays plus développés, qui avaient généralement un meilleur accès à Internet, étaient plus susceptibles de présenter des niveaux plus faibles de suicide après ajustement, la nature transversale des données et le devis écologique ne permettent pas d'établir un lien de causalité. Ces résultats sont également importants, car ils montrent qu'il faut tenir compte du statut socioéconomique national lorsqu'on étudie les relations entre les technologies numériques et l'état de santé des populations.

Keywords: Suicide mortality, ecological study, digital access, Internet use, socioeconomic development.

Introduction

Suicide is a major global public health concern and one of the leading causes of death worldwide, with more than 700,000 deaths each year (1). In 2021, it was the third leading cause of death in the 15–29 age group, and nearly 75% of all suicides occur in low- and middle-income countries (1-2). Suicide mortality varies significantly by country-from an estimated 6 per 100,000 in low-income countries to about 11 per 100,000 in high-income countries. Conversely, global internet penetration has rapidly expanded the availability of information and modes of communication and interaction, from an estimated 11% of users in low-income countries to nearly 85% in high-income countries.

The relationship between internet use and mental health outcomes, including suicide-related behaviors, has been the subject of considerable debate in the literature. A systematic review by Marchant et al. (2017) examining internet use, self-harm, and suicidal behavior in young people identified a complex and bidirectional pattern (3). Their findings indicated that while problematic internet use and exposure to harmful online content are associated with increased self-harm and suicidal ideation, internet access could also facilitate help-seeking behaviors and connection to supportive communities. Similarly, other research has documented both the potential risks of cyberbullying, social comparison, and access to pro-suicide content, as well as the benefits of online mental health resources, crisis support services, and reduced social isolation (4-5). These mixed results imply that the relationship between access and suicide results may be complex and highly conditional on a number of environmental factors: types of internet usage, the type of available information, and the socio-economic milieu.

Among indicators of socioeconomic development, at the population level, GDP per capita, literacy, life expectancy, electrical power, and school enrollment are known predictors of mental health conditions. Prior studies suggest that increased levels of education and income in certain populations may be linked to decreased risk of suicide in other studies, although such relations can vary considerably among locations and populations. (6-7). For instance, the well-documented paradox wherein wealthier nations often report higher suicide rates than lower-income countries has been attributed to differences in reporting accuracy, age structure, cultural factors, and access to lethal means (8). The interaction between technological infrastructure and these traditional socioeconomic determinants remains poorly understood, particularly at the global level.

Few studies have investigated the relationship between global internet penetration and suicide mortality at the ecological level while controlling for the effects of socioeconomic development. Such an ecological investigation is important for several reasons. First, as digital infrastructure continues to spread globally, it is critical that policy decisions surrounding digital infrastructure investment are informed by an understanding of technology's impact on population mental health. Second, determining if an association between internet access and suicide is modified by the level of national development will help inform appropriate strategies for targeting mental health interventions to prevent suicide. Third, ecological studies can help identify patterns that exist at the population level that are not observable at the individual level and which can serve as a source of hypotheses for future in-depth study.

This study sought to examine ecological associations between internet penetration, socioeconomic indicators, and suicide mortality from 2015 to 2023 using country-level data. Specifically, this study aimed to: (1) describe global variation in internet access and suicide mortality across income groups, (2) assess the crude association between internet penetration and suicide rates, (3) evaluate how this association changes after accounting for key socioeconomic confounders, and (4) explore whether the relationship between internet access and suicide mortality varies by level of national development. By addressing these aims through hierarchical modeling approaches that account for the complex interdependencies among development indicators, this research contributes to understanding the broader context in which digital infrastructure expansion occurs and its relationship with population mental health outcomes. As internet access continues to expand rapidly across low- and middle-income countries, understanding how digital connectivity intersects with suicide mortality within different socioeconomic contexts is increasingly urgent for global health policy. These findings can help inform evidence-based decisions about digital infrastructure investments, identify settings where internet expansion may need to be coupled with mental health supports, and guide the development of targeted suicide prevention strategies that account for both technological and socioeconomic realities across diverse national contexts.

Methods and Materials

An ecological, cross-national study design was employed using publicly available country-level indicators retrieved from the World Bank World Development Indicators database spanning 2015 to 2023. Correlations were explored between national internet penetration and age-standardized suicide mortality while accounting for key socioeconomic development indicators. Countries were eligible for inclusion if data were available for both the primary exposure and outcome variables for at least one year during the study window. For countries with multiple years of available data, mean values from 2015 to 2023 were calculated to represent overall country-level conditions and to reduce the effect of interannual fluctuations.

The primary outcome variable was the age-standardized suicide mortality rate per 100,000 population, as reported in the World Bank World Development Indicators. Meaningful international comparisons were facilitated by age standardization to account for cross-national differences in age distribution. The primary exposure variable was internet penetration, measured as the percentage of the population reporting internet use. This indicator

captures national access to digital infrastructures and information technologies. Socioeconomic covariates were selected a priori based on theoretical relevance and prior literature on the social determinants of health. These variables included adult literacy rate (percentage of the population aged fifteen and older who can read and write), gross domestic product (GDP) per capita (constant US dollars), gross school enrollment rate, life expectancy at birth (years), unemployment rate (percentage of the labor force), percentage of the population with access to electricity, and annual population growth rate. GDP per capita was log-transformed before regression analyses to reduce skewness and to account for proportional changes across national income groups. Continuous variables were mean-centered to aid interpretation and reduce multicollinearity in multivariable and interaction models.

Descriptive analyses were used to describe the country-level distribution of suicide mortality, internet penetration and socioeconomic indicators. Summary statistics including means, standard deviations, and ranges were calculated for the full sample and stratified by World Bank income group. Geographic variation in suicide mortality and internet penetration was examined using global choropleth maps created using standard geographic visualization packages. Bivariate associations among internet penetration, suicide mortality, and socioeconomic indicators were evaluated using Pearson correlation coefficients. These analyses provided an initial assessment of the direction and magnitude of associations between variables.

Multivariable associations were evaluated using hierarchical ordinary least squares regression models. The modeling strategy was designed to assess how the estimated association between internet penetration and age-standardized suicide mortality changed with progressive adjustment for national socioeconomic factors. The initial model specification included internet penetration as the sole predictor. Subsequent models sequentially introduced covariate blocks: demographic and health indicators (life expectancy and population growth), economic indicators (log GDP per capita), infrastructure and labor market indicators (electricity access and unemployment), and education-related measures (literacy rate and school enrollment). This sequential modeling strategy allowed assessment of potential confounding and the extent to which development indicators accounted for the unadjusted association between internet penetration and suicide mortality.

To evaluate effect modification by development stage, interaction terms were included between internet penetration and key socioeconomic indicators (e.g., internet × log GDP per capita and internet × literacy rate). Variable importance plots were generated using standardized regression coefficients from models predicting GDP per capita, with importance quantified as the absolute magnitude of standardized beta coefficients. The relative contribution of each predictor in explaining variation in national income was illustrated by these plots, both overall and stratified by World Bank income classification. Population-weighted models were used in sensitivity analyses to evaluate the influence of country population size on aggregate associations.

Coefficients are reported with 95% confidence intervals; two-sided tests were performed, and statistical significance was set at $\alpha = 0.05$. Model diagnostics and robustness analyses were conducted to evaluate assumptions and the consistency of findings. Multicollinearity was assessed using variance inflation factors and addressed by re-estimating alternative specifications when collinearity was high. Influential observations were identified using leverage statistics and Cook's distance, and sensitivity analyses excluding high-leverage countries were conducted. Alternative specifications explored included transformation of the outcome when appropriate, and quantile regression was used to examine heterogeneity across the distribution of suicide mortality. For countries with adequate temporal coverage, fixed-effects panel models were estimated as an additional sensitivity analysis. Patterns of missing data were summarized, and primary analyses were conducted using complete-case data when missingness was minimal, with multiple imputation by chained equations used as a sensitivity analysis when missingness exceeded predefined thresholds. All data management, statistical analyses, and visualizations were performed using the World Bank World Development Indicators dataset and the R statistical environment. Since the study relied exclusively on aggregated, publicly available country-level data, institutional ethics review and informed consent were not required.

Results

Descriptive characteristics of the study sample

The analytic sample included countries with available data on internet penetration, suicide mortality, and key socioeconomic indicators for at least one year from 2015–2023. Significant cross-national variation was observed across all study variables. Internet penetration ranged from approximately 2.2%–100%, reflecting substantial disparities in access to digital infrastructure worldwide. Age-standardized suicide mortality rates varied from approximately 0.63–29.53 deaths per 100,000 population. When stratified by World Bank income classification, clear gradients were evident (Table 1). High-income countries had substantially higher average internet penetration (mean ≅ 85%) compared to approximately 11% in low-income nations. Suicide mortality rates were also higher on average in high-income countries (≅ 9–11 per 100,000) compared to low-income countries (≅ 6.5 per 100,000), with middle-income countries showing intermediate patterns. Socioeconomic indicators including GDP per capita, life expectancy, electricity access, school enrollment, and literacy rates increased consistently across income categories, while unemployment and population growth showed more heterogeneous patterns without a monotonic relationship to income group. These descriptive results demonstrate substantial clustering of development-related variables, underscoring the need for multivariable modeling to account for confounding and collinearity.

Table 1. Descriptive statistics of study variables by income group. Summary statistics showing mean values and standard deviations for internet penetration (% of population), suicide mortality (age-standardized deaths per 100,000), and socioeconomic indicators stratified by World Bank income classification (low-income, lower-middle-income, upper-middle-income, high-income). GDP = gross domestic product. Data obtained from World Bank World Development Indicators, 2015–2023.

income	variable	mean	sd	min	max
High income	electricity	99.94	0.11	99.70	100.00
	gdp	31891.64	18962.85	13433.92	80056.13
	internet	84.54	9.71	64.57	100.00
	life_exp	80.37	2.79	72.81	83.60
	literacy	97.55	1.44	93.04	99.70
	pop_growth	0.73	1.79	-4.17	4.83
	school_enroll	107.70	9.16	86.20	124.85
	suicide	9.15	7.16	1.03	23.40
	unemployment	7.43	5.28	1.80	22.06
Low income	electricity	26.37	17.44	8.40	71.50
	gdp	670.09	228.25	210.01	996.38
	internet	11.29	7.16	2.20	37.62
	life_exp	60.37	3.54	51.60	66.35
	literacy	53.08	17.38	22.31	76.72
	pop_growth	2.64	0.36	1.72	3.22
	school_enroll	43.46	16.10	20.19	107.03
	suicide	6.85	2.12	3.46	12.48
	unemployment	3.86	2.43	1.03	10.76
Lower middle income	electricity	87.37	17.40	26.20	100.00
	gdp	2867.53	1472.33	877.26	9174.54
	internet	40.59	19.03	10.00	82.18
	life_exp	69.58	5.10	52.19	78.26
	literacy	81.75	15.51	43.59	100.00
	pop_growth	1.41	1.02	-3.22	3.26
	school_enroll	71.67	19.02	26.09	98.33
	suicide	6.79	5.30	0.63	26.73
	unemployment	7.02	6.05	0.12	26.39
Upper middle income	electricity	97.25	7.91	49.70	100.00
	gdp	7360.53	2168.90	3880.69	12425.03
	internet	64.89	13.12	28.81	88.21
	life_exp	73.90	3.65	60.81	79.71
	literacy	94.81	3.63	80.20	99.97
	pop_growth	1.04	0.82	-0.54	3.48
	school_enroll	95.04	13.69	54.08	124.33
	suicide	7.22	5.41	0.76	29.53
	unemployment	8.90	6.51	0.60	34.01

Geographic distribution of internet penetration and suicide mortality

Figures 1 and 2 represent the spatial distribution of internet penetration and suicide mortality globally and their respective distributions by income level. The data showcase considerable geographic clustering of the suicide mortality data, where the highest reported rates appear in Central Asia, Eastern Europe, East Asia, and parts of South America and Africa. On the other hand, much of Sub-Saharan Africa, along with parts of South America and the Middle East, have very low suicide mortality data. The geographic distribution of Internet penetration data is equally stark, with the majority of countries in North America, East Asia, Western Europe, and Oceania considered to have universal Internet access, whilst a large portion of countries in South Asia and Sub-Saharan Africa have penetration rates of under 20%. Visual observation clearly shows some geographical overlap between locations with high internet penetration and those with higher rates of suicide mortality, such as wealthier areas of East Asia and Europe. However, this is not always true, there are some highly connected countries with moderate suicide rates and some with very low internet penetration rates with high rates. This indicates that internet penetration cannot simply be interpreted without regard to the overarching issues such as geography and socioeconomics.

Correlation structure and bivariate associations

Pearson correlation analyses (Figure 2) revealed that internet penetration was strongly associated with socioeconomic development indicators. Internet use showed strong positive correlations with GDP per capita (r ≅ 0.70), literacy rate (r ≅ 0.60), and life expectancy (r ≅ 0.65), as well as with school enrollment and electricity access. In contrast, the unadjusted association between internet penetration and suicide mortality was weak and positive, suggesting that countries with higher internet usage tended to report slightly higher rates of suicide mortality at the ecological level. The relationship among the development indicators had moderate to strong correlation, particularly between GDP per capita, life expectancy, literacy, and electricity (implying that the variables were indeed very correlated). Therefore, hierarchical multiple regression evaluated the independent effects of internet use on suicide mortality, while controlling for socioeconomic development.

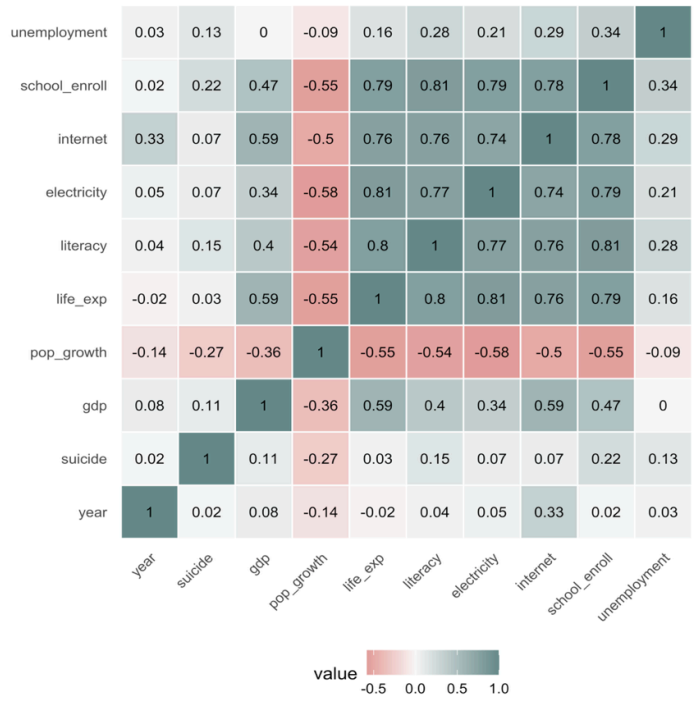

Figure 2. Correlation matrix of study variables. Pearson correlation coefficients between internet penetration, suicide mortality, and socioeconomic indicators. Coefficient magnitude shown by color intensity and circle size. GDP = gross domestic product. Data obtained from World Bank World Development Indicators, 2015–2023.

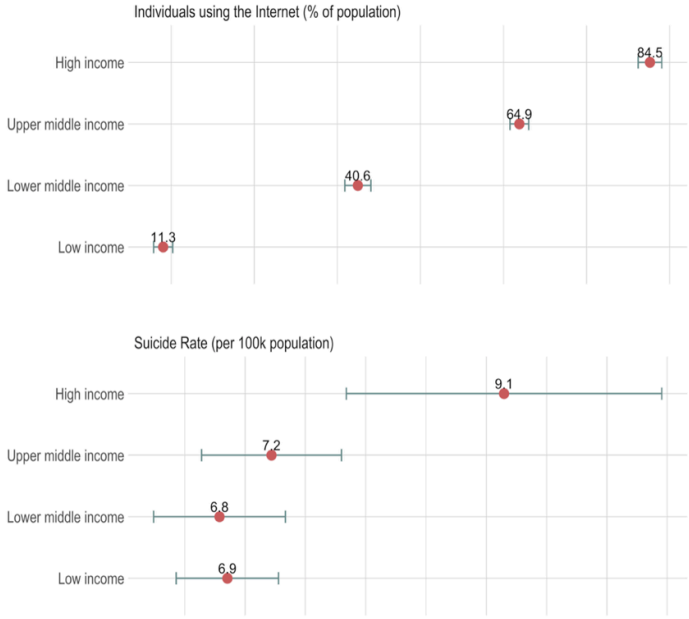

Figure 1. Internet use and suicide rates by income groups. Box plots showing distribution of internet penetration (% of population) and age-standardized suicide mortality rates (per 100,000) across World Bank income groups (low-income, lower-middle-income, upper-middle-income, high-income). Boxes show interquartile range, horizontal lines show medians. Data obtained from World Bank World Development Indicators, 2015–2023.

Hierarchical regression models

Hierarchical regression models assessed how the association between internet penetration and suicide mortality changed after sequential adjustment for socioeconomic development indicators (Table 2). In the unadjusted model, internet penetration showed a small positive association with suicide mortality that did not reach statistical significance. After adjustment for GDP per capita and life expectancy, the magnitude of the internet coefficient was substantially attenuated, indicating that the crude positive association was largely explained by differences in demographic

Table 2. Hierarchical regression models predicting suicide mortality rate. Unstandardized beta coefficients with 95% confidence intervals from four sequential hierarchical regression models. Model I: internet penetration only. Model II: adds GDP per capita and life expectancy. Model III: adds electricity access, unemployment, literacy, and school enrollment. Model IV: adds population growth. GDP = gross domestic product. ***p < 0.001; **p < 0.01; *p < 0.05. Data obtained from World Bank World Development Indicators, 2015–2023.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Characteristic	**Beta**	**95% CI** [1]	**Beta**	**95% CI** [1]	**Beta**	**95% CI** [1]	**Beta**	**95% CI** [1]	**Beta**	**95% CI**
internet	0.07	-0.04, 0.18	0.01	-0.13, 0.14	-0.16	-0.34, 0.03	-0.28	-0.47, -0.08	-0.30	-0.50, -0.10
gdp			0.11	-0.03, 0.24	0.20	0.07, 0.34	0.20	0.05, 0.34	0.21	0.07, 0.36
pop_growth					-0.32	-0.45, -0.19	-0.29	-0.42, -0.17	-0.30	-0.43, -0.17
life_exp					-0.46	-0.66, -0.26	-0.55	-0.78, -0.33	-0.54	-0.77, -0.31
literacy					0.38	0.19, 0.58	0.24	0.04, 0.44	0.23	0.03, 0.43
electricity							-0.08	-0.29, 0.13	-0.07	-0.28, 0.14
school_enroll							0.49	0.28, 0.69	0.46	0.25, 0.67
unemployment									0.07	-0.04, 0.18
R^2	0.005		0.013		0.145		0.202		0.206	
Adjusted R^2	0.002		0.006		0.131		0.184		0.185	

[1] CI = Confidence Interval

and economic development. With the inclusion of education (literacy and school enrollment), unemployment, infrastructure (electricity access), and population growth, the association reversed direction. In the fully adjusted model, higher internet penetration was associated with lower suicide mortality (β = -0.30; 95% CI: -0.50, -0.10), suggesting that among countries at comparable levels of socioeconomic development, greater internet access was correlated with lower population-level suicide mortality. This ecological association corresponds to approximately 0.3 fewer deaths per 100,000 people for each 10 percentage-point increase in national internet penetration, holding other factors constant. Several socioeconomic variables remained independently associated with suicide mortality. Life expectancy showed a positive association, consistent with demographic composition effects in countries with older age distributions. School enrollment demonstrated a strong inverse association at the ecological level. GDP per capita and electricity access showed weaker associations after adjustment, while population growth and unemployment did not remain statistically significant predictors in the fully adjusted model.

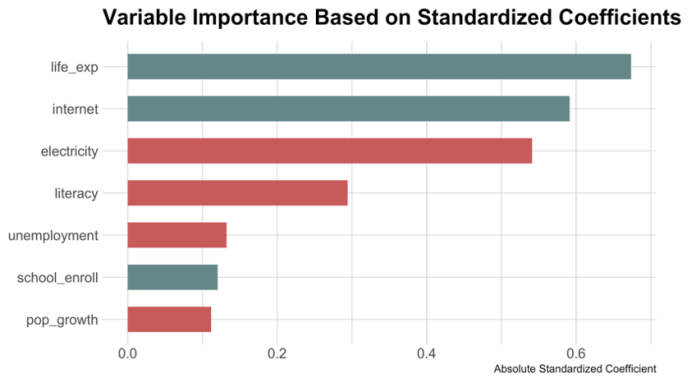

Figure 3. Variable importance for predictors of GDP per capita. Variable importance quantified as absolute magnitude of standardized regression coefficients from models predicting GDP per capita. Positive bars indicate positive associations; negative bars indicate inverse associations. GDP = gross domestic product. Data obtained from World Bank World Development Indicators, 2015–2023.

Variable importance analysis

The variable importance analysis used standardized regression coefficients from models predicting GDP per capita. Variable importance was measured as the magnitude (absolute value) of standardized coefficients in models explaining national income; higher standardized coefficients indicate greater explanatory contribution. The variable with the highest importance was life expectancy, followed by internet access and electricity access; literacy and schooling were moderately correlated with national income. Unemployment and population growth were inversely associated with national income. This illustrates the background context for the observed changes in the association of internet access and suicide mortality following adjustment: it is not an isolated variable but is associated with other indicators of development.

Effect modification by socioeconomic development

Interaction analyses showed that the association between internet penetration and suicide mortality differed by national level of development. Internet penetration interacted with GDP per capita and literacy rate; countries with greater levels of economic development and literacy demonstrated a greater inverse

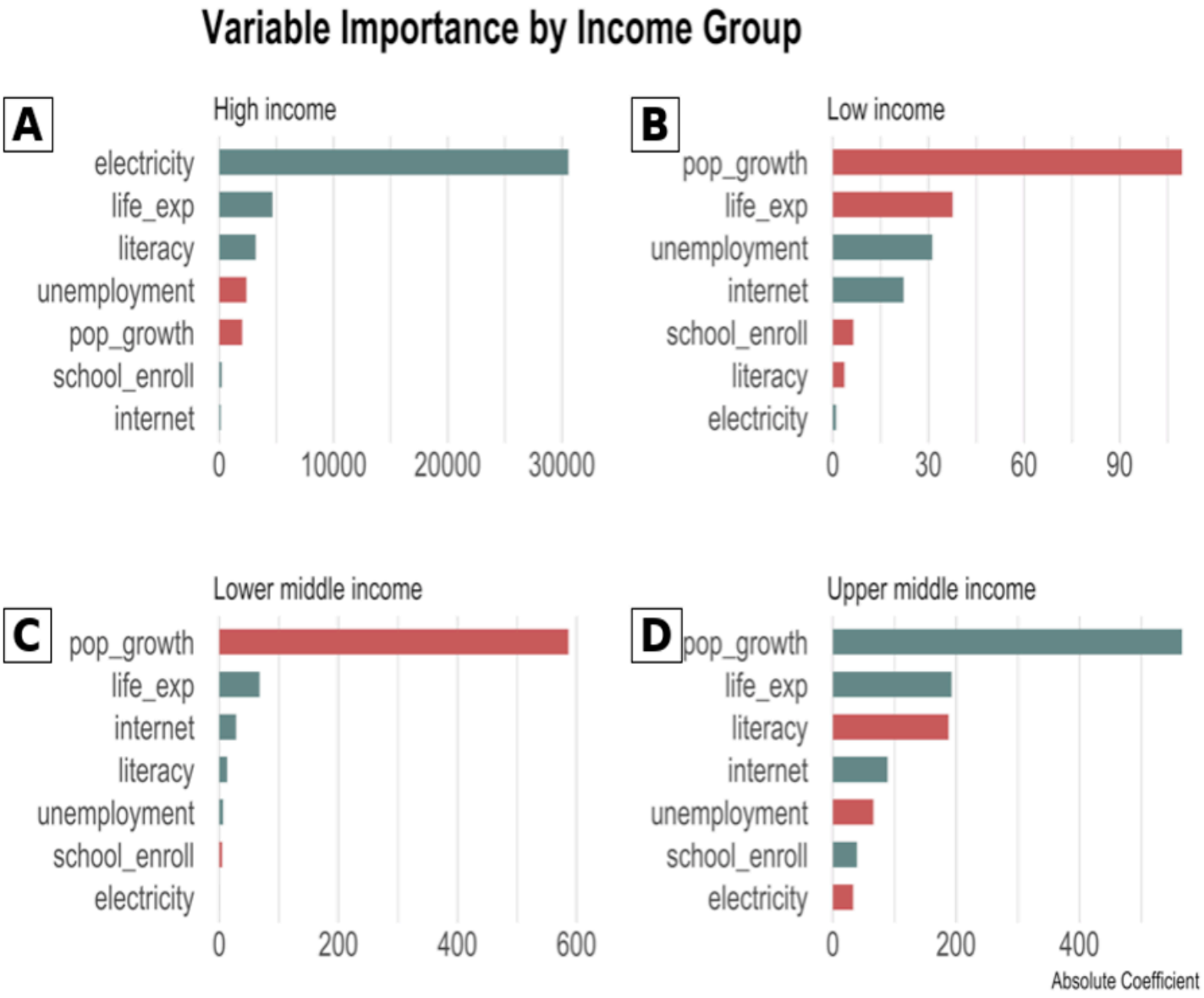

Figure 4. Variable importance stratified by income group. Panel A reports results for high-income countries, Panel B reports results for low-income countries, Panel C reports results for lower-middle-income countries, and Panel D reports results for upper-middle-income countries. Variable importance stratified by World Bank income classification shows the difference in variables that are predictive of GDP per capita at different levels of development. Positive bars correspond to positive associations while negative bars correspond to negative associations.GDP is gross domestic product. Data are from the World Bank World Development Indicators (2015-2023).

relationship between internet penetration and suicide mortality. For countries with lower literacy or lower income, the association was weaker and in some cases, non-significantly distinguishable from null. These analyses suggest that the ecological association between internet penetration and suicide mortality is more significant in environments with greater levels of socioeconomic development. Figure 4 reveals results of variable importance analysis by World Bank income levels; although the analysis results vary considerably across levels of development, associations between other development variables and GDP per capita also appear to differ by economic level of country development. Among high-income countries, life expectancy was the most significant determinant of variation in GDP, followed by internet use and school enrollment. Internet use was the most important predictor of GDP for upper-middle-income countries, followed by literacy rate and life expectancy. For lower-middle-income countries, the analysis showcased a pattern whereby unemployment had strong negative importance for GDP per capita, but life expectancy and internet use were positively associated with GDP per capita. In low-income countries, population growth was strongly negatively associated with GDP per capita, and access to electricity was among the strongest positively associated variables in the model.

Sensitivity analyses and robustness checks

A series of sensitivity analyses confirmed the robustness of the main findings. Centering predictors and alternative model specifications addressed moderate collinearity among development indicators. Exclusion of high-leverage countries did not substantially alter the direction or magnitude of the internet coefficient. Alternative outcome specifications, including transformations of suicide mortality, yielded consistent results. Quantile regression showed that the inverse association between internet penetration and suicide mortality was strongest near the median of the distribution and weaker at the extremes. Fixed-effects panel models for countries with sufficient temporal coverage produced directionally consistent but less precise estimates, likely due to limited within-country variation over the relatively short study period.

Discussion

This ecological study examined associations between internet penetration, socioeconomic development, and suicide mortality across countries from 2015 to 2023. At the crude ecological level, internet use showed a positive correlation with suicide mortality, a pattern largely explained by the tendency for higher-income countries to have both greater internet access and higher recorded suicide rates. However, after accounting for socioeconomic development through hierarchical modeling, a different pattern emerged. Among countries at comparable levels of development, higher internet penetration was associated with lower rates of suicide mortality. This reversal demonstrates that the crude positive association observed globally reflects confounding by national development rather than a direct relationship between internet access and suicide risk.

It is critical to emphasize that these findings are ecological in nature and describe associations at the country level. Ecological associations cannot be used to infer individual-level relationships —a limitation known as the ecological fallacy (9). A country with high internet penetration and low suicide mortality does not necessarily mean that individuals who use the internet are less likely to die by suicide. Individual-level mechanisms may differ substantially from population-level patterns. For example, while the ecological analysis suggests an inverse association after accounting for development, individual-level studies have documented both beneficial and harmful effects of internet use on mental health, with outcomes depending heavily on how individuals engage with digital technologies (3).

The hierarchical regression results illustrate how sequential adjustment for confounders alters the estimated association. In the unadjusted model, internet penetration showed a small positive but non-significant association with suicide mortality. The introduction of GDP per capita and life expectancy moved the internet coefficient toward zero, indicating that wealthier and healthier countries largely explained the crude association. The addition of electricity access, education, population growth, and unemployment reversed the direction of the association and became statistically significant, with higher internet penetration associated with lower suicide rates. This pattern suggests that when comparing countries at similar developmental stages, internet access is correlated with reduced population-level suicide mortality. However, this association should not be interpreted causally given the cross-sectional design and potential for unmeasured confounding. Moreover, as an ecological study, the risk of ecological fallacy prevents the extrapolation of these country-level associations to individual-level relationships.

These findings both align with and diverge from prior research in important ways. The systematic review by Marchant et al. (2017) highlighted the complexity of internet-mental health relationships at the individual level, documenting both risks (cyberbullying, exposure to harmful content) and benefits (access to support, reduced isolation). The ecological findings suggest that at the population level, in contexts with strong socioeconomic infrastructure, internet access may co-occur with lower suicide mortality. However, the results contrast with concerns that increased internet access might uniformly increase suicide risk through mechanisms such as social media-related distress or access to information about suicide methods. The reversal of the association after adjustment for development indicators suggests that the apparent positive correlation between internet use and suicide in crude comparisons is attributable to confounding by national development level rather than internet access itself being harmful.

Several socioeconomic indicators were independently associated with suicide mortality. Life expectancy shows a positive association, consistent with the demographic reality that countries with older populations have higher proportions of individuals in age groups with elevated suicide risk. School enrollment

demonstrates a strong inverse association, suggesting that broader access to education may be associated with population-level suicide prevention, potentially through economic opportunity, social integration, or mental health literacy. These associations align with prior literature linking education and economic opportunity to mental health outcomes (6). The correlation matrix reveals why unadjusted analyses can be misleading in ecological research. Internet penetration was strongly correlated with life expectancy, literacy, GDP, and electricity access, reflecting the tendency for development indicators to co-occur rather than evolve independently. Without controlling for this clustering, internet use appears associated with suicide mortality simply because both correlate with economic development and modernization. This underscores a fundamental challenge in ecological research: separating the independent contribution of specific exposures from the broader context in which they occur.

The interaction analyses reveal that the association between internet penetration and suicide mortality varied by development context, being strongest in settings with higher literacy rates and GDP per capita. This heterogeneity suggests that internet access may represent different realities across developmental stages. In more developed countries with robust healthcare systems, mental health services, and educational infrastructure, greater connectivity may facilitate access to supportive resources. In less developed settings, limitations in infrastructure, affordability, or content quality may constrain potential benefits. However, these interpretations are speculative and would require individual-level data to test mechanistically. The variable importance analyses across income groups revealed substantial heterogeneity in which development indicators best predicted national income. In high-income countries, life expectancy and internet use were most strongly associated with GDP variation. In upper-middle-income nations, internet use emerged as the strongest predictor, highlighting the role of digital infrastructure during economic transitions. In lower-middle-income countries, unemployment played a larger role, while in low-income nations, electricity access and population growth were most influential. These patterns suggest that technological infrastructure interacts differently with development depending on a country's developmental stage, which may partly explain why the internet-suicide association varied across contexts.

Limitations

This study has several important limitations inherent to its design and data structure. First and most critically, the analysis is ecological, with all variables measured at the country level. This design precludes inference about individual-level relationships, a limitation known as ecological fallacy (9). Associations observed at the population level cannot be assumed to hold at the individual level. For example, while higher national internet penetration associates with lower suicide mortality after adjustment for development, this pattern does not mean that individual internet users have lower suicide risk. Individual-level mechanisms may operate differently, and the relationship between personal internet use and suicide risk likely depends on numerous factors that ecological data fail to capture, including patterns of use, content accessed, pre-existing mental health status, and availability of offline support.

Second, the cross-sectional nature of these data prevents any causal interpretation. The design makes it impossible to determine whether internet penetration influences suicide mortality, whether countries experiencing declining suicide mortality invest more in internet infrastructure, or whether unmeasured common causes drive both. Temporal precedence cannot be established from cross-sectional ecological data. While sensitivity analyses using fixed-effects models for countries with adequate temporal coverage provide some support for consistency over time, the limited time window (2015–2023) and substantial missing data constrain these analyses.

Third, suicide reporting accuracy and completeness vary substantially across countries. Underreporting and misclassification are common, particularly in low-income countries and settings where suicide carries social stigma (7). The geographic maps revealed regions with missing or incomplete data, especially in parts of sub-Saharan Africa and small island states. If suicide is systematically underestimated in certain regions, biases in observed differences between income groups may arise. This measurement error could produce spurious associations or mask true patterns.

Fourth, the study aggregated data across multiple years to form a single cross-section, which limits observation of temporal trends within individual countries. While this approach reduces the impact of year-to-year fluctuations, it prevents examination of how changes in internet access over time relate to changes in suicide mortality within the same country. Such within-country analyses would provide stronger evidence about temporal relationships but remain unfeasible with the available data. Fifth, internet penetration is a crude measure of digital access. It captures the proportion of the population with internet access but does not measure how the internet is used, what content users access, the quality of connectivity, or whether usage patterns are beneficial or harmful for mental health. Different forms of online engagement may have divergent mental health implications, which aggregate penetration rates cannot differentiate. Finally, despite extensive adjustment for socioeconomic confounders, unmeasured confounding remains possible. Cultural factors, mental health service availability, availability of lethal means, substance use patterns, and other country-level characteristics that correlate with both internet access and suicide mortality could account for some or all of the observed associations. The strong correlations among development indicators also introduce multicollinearity, which can increase uncertainty in coefficient estimates despite efforts to address this through centering and alternative specifications.

Future Directions

Future research should build on these ecological findings in

several ways. Most importantly, individual-level data linking internet use patterns, mental health status, and suicide outcomes would enable direct evaluation of the mechanisms that these population-level results suggest. Longitudinal cohort studies following individuals over time as their digital engagement varies would help establish temporal precedence and support stronger causal inference than is possible with cross-sectional ecological data. More detailed measures of digital engagement are needed. Differentiating between types of internet use—social media, entertainment, education, health information seeking—could reveal which aspects of connectivity are most relevant for mental health. Research should also examine potentially harmful online exposures (cyberbullying, pro-suicide content) alongside potentially beneficial ones (crisis resources, social support) to understand the overall association between internet access and mental health outcomes.

Longitudinal country-level studies tracking nations as internet access expands would strengthen understanding of temporal relationships. Natural experiments—such as policy changes that rapidly expand internet access in specific regions—could provide quasi-experimental leverage for assessing whether changes in internet penetration precede changes in suicide mortality. Including indicators of mental health service availability, quality of online mental health resources, cultural attitudes toward suicide and help-seeking, and social support systems would allow more comprehensive modeling of the context in which internet access operates. This would help explain why associations between internet penetration and suicide mortality vary across income groups in this study. Finally, improving suicide mortality surveillance in low-income countries is essential. Strengthening vital registration systems and reducing underreporting would reduce measurement bias and enable more accurate assessment of global mental health patterns. Without improved data quality in these settings, differential measurement error across regions will continue to limit ecological studies.

Conclusion

This ecological study examined associations between internet access, socioeconomic development, and suicide mortality at the country level from 2015 to 2023. The analyses reveal that the apparent relationship between digital access and suicide outcomes varies substantially depending on how the study addresses socioeconomic confounding. Crude analyses suggested a positive association between internet penetration and suicide mortality, but this pattern was largely explained by the tendency for wealthier countries to have both higher internet access and higher recorded suicide rates. After hierarchical adjustment for educational, demographic, economic, and infrastructural factors, higher internet penetration was associated with lower suicide mortality among countries at comparable developmental stages.

However, several critical limitations constrain interpretation of these findings. Most importantly, ecological associations cannot be used to infer individual-level relationships. The ecological fallacy means that population-level patterns may not reflect individual-level mechanisms. Additionally, the cross-sectional design precludes causal inference, preventing determination of whether internet access influences suicide mortality or whether both are influenced by common underlying factors. Variations in suicide reporting accuracy across countries, particularly systematic underreporting in low-income settings, introduce measurement error that may bias estimates. The interaction and stratified analyses revealed that associations between internet penetration and both economic development and suicide mortality varied substantially across income groups. This heterogeneity suggests that digital infrastructure operates within different socioeconomic contexts at different stages of development. In high-income countries with established healthcare and educational systems, internet access may co-occur with features that support mental health. In lower-income settings, basic infrastructure needs and demographic pressures may be more salient.

These findings suggest that simplistic narratives about internet access being uniformly harmful or beneficial for mental health are likely inadequate. The relationship between technology and population mental health appears to be embedded within broader patterns of socioeconomic development, and the direction and magnitude of associations depend critically on the developmental context and the presence of confounding factors. From a policy perspective, these results underscore that expanding internet access alone is unlikely to reduce suicide mortality without concurrent investments in healthcare, education, and social infrastructure. Future research should move beyond ecological associations to examine individual-level mechanisms through which digital engagement relates to mental health across diverse socioeconomic settings. Longitudinal designs that can establish temporal precedence, more granular measures of internet use quality and content, and improved suicide surveillance globally are all necessary to advance understanding in this area. Nonetheless, this study provides evidence that the relationship between digital development and population mental health is complex, context-dependent, and inseparable from broader socioeconomic development processes. Mental health policies for the population should thus take technological infrastructure into account within a broad context, including education, opportunity, health care services, and support.

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