Impact of Human Development status on maternal mortality rate and the moderation role of Government health expenditure

Chinenye Kate Ezennaya

Naw Mu Aye, Naw Mu Aye

University of Niagara Falls Canada

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Prof. Patty Zakaria

DAMO:500-6: Principal of Analytics

Faculty of Master's in Data Analytics

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Maternal mortality remains a critical global health challenge and a stark marker of inequality, reflecting disparities in healthcare access, education, and social safety nets. In 2017, the World Health Organization (WHO) reported that approximately 295,000 women died due to pregnancy or childbirth complications, with 94% occurring in low- and middle-income countries (WHO, 2019). These largely preventable deaths emphasize the urgent need for strategic interventions to eliminate systemic barriers and improve maternal health outcomes.

The Human Development Index (HDI), which combines life expectancy, education, and income, is a key determinant of maternal health outcomes. Higher HDI levels correlate with lower maternal mortality rates, as advancements in education and income enhance access to quality healthcare (UNDP, 2024). However, the relationship is not straightforward, as other factors, such as government health expenditure (GHE), can influence outcomes. GHE, which reflects the proportion of national resources allocated to healthcare, is a critical indicator of governmental commitment to improving health service access and quality, particularly for underserved populations (World Bank, 2023).

While the independent impacts of HDI and GHE on health outcomes are well-documented, limited research has explored whether GHE moderates the HDI-maternal mortality relationship. This study addresses this gap by analyzing global data from 2018 to 2020 to determine whether GHE strengthens or weakens HDI's influence on maternal health. By exploring the interaction between development indicators and public health investments, the research aims to provide evidence-based recommendations for reducing maternal mortality and

achieving Sustainable Development Goal (SDG) 3.1, which seeks to reduce global maternal mortality to fewer than 70 deaths per 100,000 live births by 2030 (WHO, 2024).

Background and Context

Maternal mortality highlights disparities in healthcare access, education, and social support systems. Globally, over 95% of maternal deaths occur in low- and middle-income countries, with sub-Saharan Africa and South Asia facing the highest burdens (WHO, 2024). Contributing factors include inadequate healthcare systems, limited access to skilled birth attendants, and socio-economic barriers like poverty and gender inequality.

The Human Development Index (HDI) integrates life expectancy, education, and income to provide a holistic measure of societal progress. Research consistently shows an inverse relationship between HDI and maternal mortality, with higher HDI values linked to better healthcare access and outcomes (UNDP, 2024). However, the extent to which HDI reduces maternal mortality often depends on healthcare financing.

Government Health Expenditure (GHE) reflects public investment in healthcare infrastructure, personnel, and programs. Countries with higher GHE typically achieve better maternal health outcomes, as financial resources enhance access to quality care. Despite this, the interaction between HDI and GHE remains underexplored. This study seeks to address this gap by analyzing how GHE moderates HDI's impact on maternal mortality across countries and over years.

Problem Statement

Despite global efforts, disparities in maternal mortality persist, particularly in low-HDI countries. While HDI is a recognized determinant of maternal health, its effectiveness varies

depending on public healthcare investment. The role of GHE in shaping the HDI-maternal mortality relationship remains unclear, presenting challenges for policymakers.

Key problems addressed by this study include:

1. **Understanding Variability**: Uneven reductions in maternal mortality suggest that factors like GHE influence the impact of HDI improvements.
2. **Policy Gaps**: Current policies often neglect the interactive effects of socioeconomic development and healthcare financing.

Significance of Study

Reducing maternal mortality is a cornerstone of global health initiatives, as outlined in the United Nations' SDGs. This study contributes in the following ways:

1. **Theoretical Contribution**: Examines GHE's moderating role, enhancing understanding of how public healthcare financing interacts with development indicators to influence maternal health.
2. **Policy Implications**: Offers evidence-based insights for policymakers to design targeted interventions in regions with high maternal mortality.
3. **Global Health Equity**: Highlights pathways to reduce disparities and improve maternal health outcomes, essential for achieving SDG 3.1.
4. **Practical Relevance**: Guides efficient allocation of healthcare resources to maximize maternal health improvements.

Objective

The objective of this analysis is to understand the followings points.

1. Examine the impact of Human Development (HDI) on maternal mortality rate (MMR) to understand how HDI disparities influence survival outcomes.

2. Investigate the role of government healthcare expenditure domestic (GGHED_GDP) as a moderating factor in the HDI-MMR relationship, to determine if higher spending reduces the strength of relationship between HDI and MMR.
3. Explore the combined impact of HDI and healthcare access on mortality rates during health crises, such as pandemics, to understand how socioeconomic and healthcare factors interact under extreme conditions.

Data Description

Dataset

Human Development Index (HDI), Maternal Mortality Ratio (MMR), and GGHED_GPD (Domestic General Government Health Expenditure (GGHE-D) as % Gross Domestic Product (GDP)) are used as variables in this analysis. The data are collected for the range of 2010 to 2020.

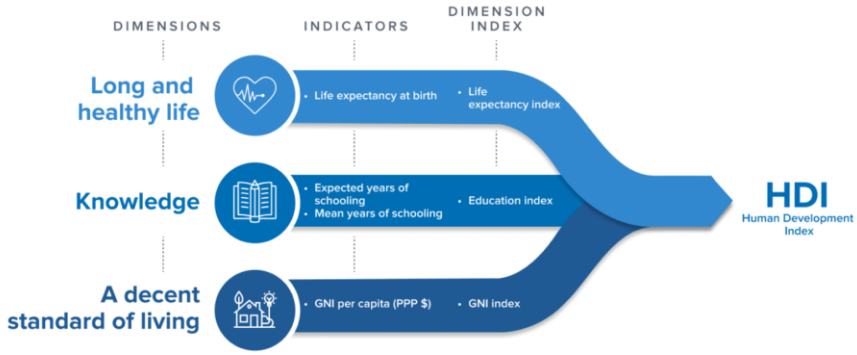
The Human Development Index contains 3-dimensions which are long and healthy life, knowledge (good education) and a decent standard of living which are measured by Life expectancy index (life expectancy at birth), education index (expected and mean year of schooling) and Gross National Income (GNI) index (GNI per capita) respectively. The HDI is estimated as the geometric mean of these indices,

HDI = (Health index * Education index * Income index) ^(1/3).

The education index is the arithmetic mean (average) of the mean years of schooling and expected years of schooling.

Figure 1:

HDI Dimensions and Indicators



HDI index dataset is obtained from Global Data Lab (*Subnational HDI - Metadata - Subnational HDI - Global Data Lab*, 2021) which collected its data through various means of survey.

Maternal Mortality Ratio (MMR) is the number of women who die from the pregnancy-related causes while pregnant or within 42 days of pregnancy termination per 100,000 live births. The dataset is obtained from World Health Organization data (*World Health Organization 2024 data*, 2024).

Domestic General Government Health Expenditure (GGHE-D) as % Gross Domestic Product (GDP) dataset is obtained from Global Health Expenditure database of World Health Organization (World Health Organization, 2014).

Data Processing

The following steps are taken in data processing.

1. Since the data used in this project comes from three different datasets, the data merging is needed to be done first. During the data merge, the name of the countries has to be tallied since some countries have aliases. Ivory Coast -> Cote d'lvore, Cape Verde -> Carbo Verde

2. Even though there is no duplication, there are some islands or countries which are part of main countries are removed from analysis for two reasons

    - To avoid taking statistics of a region in country twice and assume the territory is already counted in the main country.
    - Even though those data exist in one dataset, they don't exist in others.

    e.g. American Samoa which falls under territories of United States.

3. Missing Values: The countries where HDI, GGHED_GDP and MMR values are not available are removed since they are the main variables. Replacing value with mean value is not done so that it would not affect or alter the statistical behavior of the existing data and to obtain the true insight of the existing data.

4. Outliers:

- There is no outlier in HDI.
- Outliers from GGHED_GDP are removed since it has affected only a few countries compared to the whole sample. After removing the outliers, GGHED_GDP is free of outliers and ready for statistics analysis.

Figure 2:

Box Plot of GGHED_GDP for year 2020 with outliers

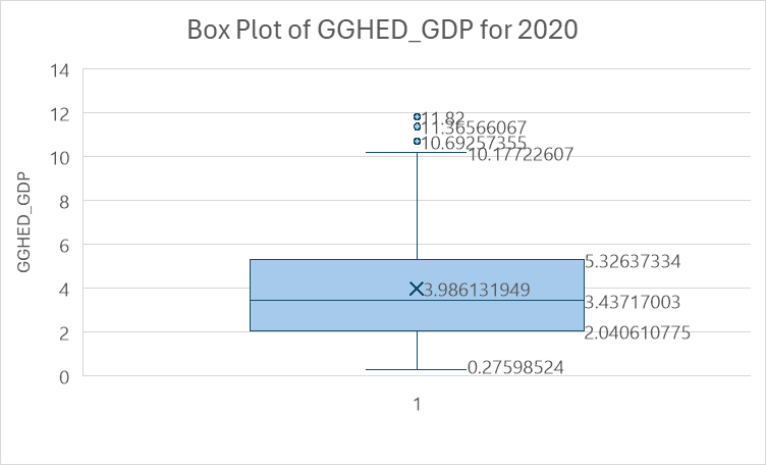
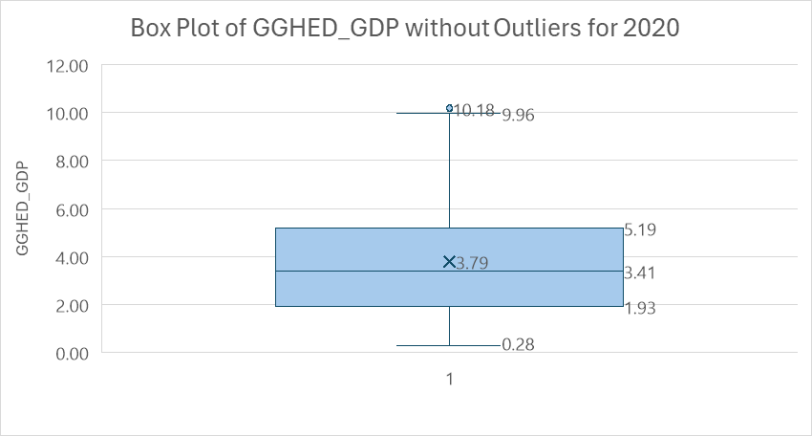


Figure 3:

Box Plot of GGHED_GDP for 2020 without outliers



- MMR has a considerable number of outliers. Moreover, after removed a set of outliers, another set of outliers emerged. Therefore, transforming to logarithmic value (LN) to mitigate the outlier effect instead of removing is used in handling outliers for MMR.

Figure 4:

Box Plot of MMR for year 2020

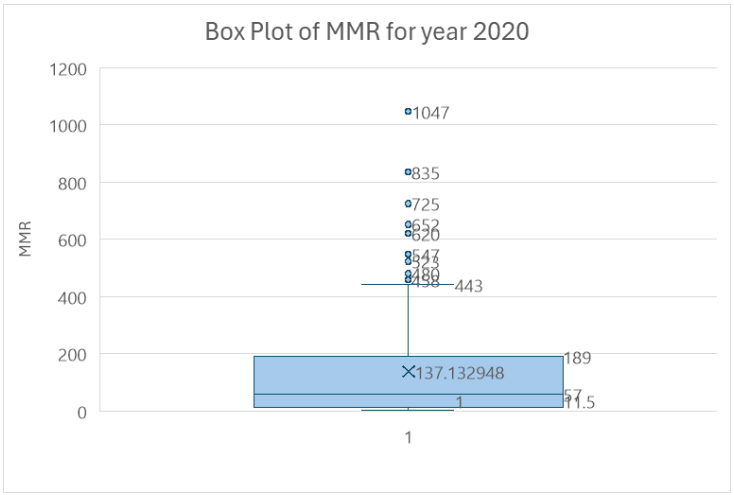
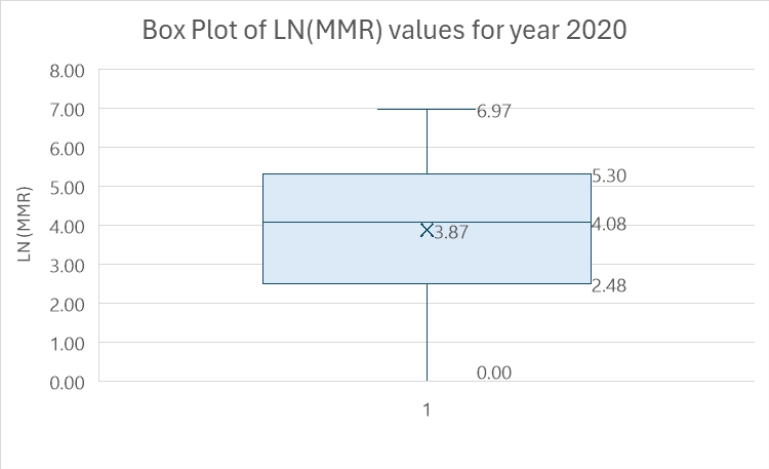


Figure 5:

Box Plot of LN(MMR) values for year 2020



5. Since GGHED_GDP values are too small with a maximum range less than 12 and the difference between them are small, GGHED_GDP values are normalized with range 0 to100. The following formula is applied to obtained normalized values.

$$Normalized\ Value = \frac{(value - \min)}{(\max - min)} * 100$$

6. To keep the consistency of data range when performing correlations or regression analysis, HDI values are also normalized with range 0 to 100.

Even though 10 years series of data are available, data analytics tasks such as hypothesis testing, correlation and causation tests are going to perform for most three recent years available in data set which are year 2018, 2019 and 2020. The outlier handling is done only for these years of data.

The countries in the following table are not going to study in this analysis, even though the countries that were removed due to outlier may be brought up during the discussion. After removing outliers and missing data countries, a total of 168 countries are considered in this study.

Table 1:

List of countries excluded in data analysis and the reasons

Countries	Reason for exclusion
Libya	Data Missing
Palestine	Data Missing
Somalia	Data Missing
South Sudan	Data Missing
Syria	Data Missing
Tanzania	Data Missing
Venezuela	Data Missing
Yemen	Data Missing
Japan	GGHED_GDP Outlier
Sweden	GGHED_GDP Outlier
United States	GGHED_GDP Outlier

Hypothesis or Research Questions

Research Questions

The following questions are used to guide the analysis of this research.

1. Is there a linear relationship between HDI and MMR?
2. Is there a linear relationship between GGHED_GDP and MMR?
3. Does GGHED_GDP act as Moderator in relationship between HDI and MMR?
4. Does higher GGHED_GDP reduce the impact of the pandemic on MMR?

Hypothesis

In this chapter, testable hypotheses are formulated to address the research questions and guide the analysis of the relation between HDI, MMR and GGHED_GDP.

1. Is there a linear relationship between HDI and MMR?

Null Hypothesis (H0): There is no direct linear relationship between HDI and MMR (Pearson correlation coefficient < 50%. The coefficient of HDI in regression between HDI and MMR is not significant, and relation R-square is less than 50)

Alternative Hypothesis (H1): There is a direct linear relationship between HDI and MMR

(Pearson correlation coefficient ≥ 50%. The coefficient of HDI in regression between HDI and MMR is significant, and relation R-square value ≥ 50)

2. ***Is there a linear relationship between GGHED_GDP and MMR***

Null Hypothesis (H0): There is no linear relationship between GGHED_GDP and MMR.

(Pearson correlation coefficient < 50%. The coefficient of GGHED_GDP in regression between GGHED_GDP and MMR is not significant, and relation R-square < 50)

Alternative Hypothesis (H1): There is a direct relationship between GGHED_GDP and MMR for countries with similar HDI levels.

(Pearson correlation coefficient ≥ 50%. The coefficient of GGHED_GDP in regression between GGHED_GDP and MMR is significant, and relation R-square ≥ 50)

3. ***Does GGHED_GDP act as Moderator in relationship between HDI and MMR?***

Null Hypothesis (H0): GGHED_GDP does not moderate the relationship between HDI and MMR. The effect of HDI on MMR is independent of GGHED_GDP.

H0: The interaction term (HDI x GGHED_GDP) has no significant effect on MMR

Alternative Hypothesis (H1): GGHED_GDP moderates the relationship between HDI and MMR. The effect of HDI on MMR depends on GGHED_GDP.

H1: The interaction term (HDI x GGHED_GDP) has a significant effect on MMR.

4. ***Does higher GGHED_GDP reduce the impact of the pandemic on MMR?***

Null Hypothesis (H0): GGHED_GDP does not mitigate the increase in MMR during the pandemic. The relationship between the pandemic and MMR is independent of GGHED_GDP.

H0: Effect of pandemic on MMR is the same regardless of GGHED_GDP.

Alternative Hypothesis (H1): GGHED_GDP mitigates the increase in MMR during the pandemic. The relationship between the pandemic and MMR depends on GGHED_GDP.

H1: Effect of pandemic on MMR decreases as GGHED_GDP increases.

Methodology

1. Is there a linear relationship between HDI and MMR?

(H0): There is no direct linear relationship between HDI and LN_MMR

(H1): There is a direct linear relationship between HDI and LN_MMR

HDI and MMR for the year 2018 to 2020 across 168 countries are gathered and analyze the relationship between them. Transformed natural logarithm value of MMR (LN_MMR) and normalized HDI values are used to achieve normalize distribution and stabilize variance.

First Pearson correlation is done over HDI and MMR to examine. The following table describes the Pearson correlation coefficient between HDI and MMR for 2018 to 2020.

Table 2:

Pearson Correlation coefficients between HDI and LN_MMR for 2018 to 2020

	2020	2019	2018
Pearson Correlation Coefficient between Norm_HDI and LN_MMR	-0.8950	-0.8983	-0.9027

Since Pearson coefficient values suggest that there is strong negative relationship between HDI and MMR, Simple Linear Regression is chosen to assess the strength and direction of the linear relationship between HDI and LN_MMR for each year.

The Linear regression model can be expressed as:

$$LN\_MMR = \beta_0 + \beta_1 * HDI + \varepsilon$$

Where:

- LN_MMR: Log of the maternal mortality rate
- HDI: Human Development Index
- β_0: Intercept

2. Is there a linear relationship between GGHED_GDP and MMR

(H0): There is no linear relationship between GGHED_GDP and MMR.

(H1): There is a direct relationship between GGHED_GDP and MMR.

GGHED_GDP and MMR for the year 2018 to 2020 across 168 countries are gathered and analyze the relationship between them. Transformed natural logarithm value of MMR (LN_MMR) and normalized GGHED_GDP is used as previous test.

First Pearson correlation is done over GGHED_GDP and MMR to examine. The following table describes the Pearson correlation coefficient between HDI and MMR for 2018 to 2020.

Table 3:

Pearson Correlation coefficients between GGHED_GDP and LN_MMR for 2018 to 2020

	2020	**2019**	**2018**
Pearson Correlation Coefficient between GGHED_GDP and LN_MMR	-0.7054	-0.6968	-0.6993

Since Pearson coefficient values is above 50% and it suggests that there is considerable negative relationship between GGHED_GDP and MMR, and therefore Simple Linear Regression is selected to assess the strength and direction of the linear relationship between GGHED_GDP and LN_MMR for each year.

3. Does GGHED_GDP act as Moderator in relationship between HDI and MMR?

H0: The interaction term (HDI x GGHED_GDP) has no significant effect on MMR

H1: The interaction term (HDI x GGHED_GDP) has a significant effect on MMR

The interaction term for moderator moderators is checked to determine if the moderator has significant effect on the relationship between two constructs. These terms are used to examine how the relationship between a predictor and outcome variable is affected by another variable.

In order to examine the effect of GGHED_GDP on the relationship between HDI and MMR as moderator, the significance of the interaction term (GGHED_GDP x HDI) is needed to be determined and analyzed. In order to perform this analysis, GGHED_GDP and HDI are normalized so that they could have a uniform range of values and improve the performance of the analysis. Then create Interaction term variable column (GGHED_GDP x HDI) by multiplying normalized GGHED_GDP and normalized HDI.

Correlation and VIF Test

After normalization, the correlation between normalized GGHED_GDP, normalized HDI, interaction term (GGHED_GDP x HDI) and LN_MMR are checked using Pearson's correlation. The following table shows the result of Pearson's correlation. It can be observed that all three predictor variables are strongly correlated with LN_MMR with minimum value of 70%.

Table 4:

Pearson Correlation Test result between LN_MMR and normalized HDI, GGHED_GDP and Interaction term (Norm_HDIxGGHED_GDP)

	LN_MMR_2020	*Norm_HDI_2020*	*Norm_gghed_gdp_2020*	*Norm_HdxGGHED_2020*
LN_MMR_2020	1			
Norm_HDI_2020	-0.89504	1		
Norm_gghed_gdp_2020	-0.70545	0.748001	1	
Norm_HDIxGGHED_2020	-0.77575	0.827861	0.958636	1

Since correlation between normalized HDI and GGHED_GDP are also correlated with more than 70%, Variance Inflation Factor (VIF) is also measured to make sure their correlation will not have negative impact on interpretation of regression model.

In order to calculate VIF values between normalized HDI and GGHED_GDP, the regressions between these two variables are performed and VIF factor is calculated with the following formula.

VIF = 1/(1- R_square)

Two regressions are performed. One setting normalized HDI as independent and GGHED_GDP as dependent and vice versa. The following table shows the results.

For both tests, R_square value 0.5595 and VIF value 1.46 resulted. VIF value 1 indicates there is no correlation between a given explanatory variable and other explanatory variables, value between 1 and 5 indicates moderate correlation between a given explanatory variable and other explanatory variables but is not serve enough to require attention. Therefore, normalized GGHED_GDP is safe to assess as a moderator.

Multi-linear regression method is selected to determine the impact of GGHED_GDP via interaction term between GGHED_GDP and HDI. The multi-linear regression formula can be described as follows:

$$LN_{MMR} = \beta_0 + \beta_1 * HDI + \beta_2 * GGHED + \beta_2 * GGHED * HDI$$

If GGHED consistently fails as a moderator, consider testing other variables that may better moderate the HDI-MMR relationship.

Explore Alternative Transformations:

Check if log-transforming GGHED improves its effect or interaction. For example: Log-transform GGHED and recompute the interaction term.

4. Does higher GGHED_GDP reduce the impact of the pandemic on MMR?

H0: Effect of pandemic on MMR is the same regardless of GGHED_GDP.

H1: Effect of pandemic on MMR decreases as GGHED_GDP increases.

To analyze this question, countries are grouped based on GGHED_GDP and compare average MMR for the same group of countries. If the increase in MMR from 2019 to 2020 is smaller in higher GGHED_GDP group, it can be deduced that GGHED_GDP has mitigation impact on the effect of pandemic.

In order to form GGHED_GDP groups across the two different years, normalization GGHED_GDP between 0 and 100 is done for both of the years. Then countries are split into four groups in quartiles, such as group with Normalized GGHED_GDP 0 to 25 as 1, 26 to 50 as 2, 51 to 75 as 3, and above 75 as 4. Average MMR values are calculated for individual groups.

The following tables show the values for average MMR and Average Normalized LN_MMR for each GGHED_GDP group for each year.

Table 5:

MMR and Normalized LN_MMR values summaries for four different groups of countries grouped by GGHED level for the year 2019 and 2020

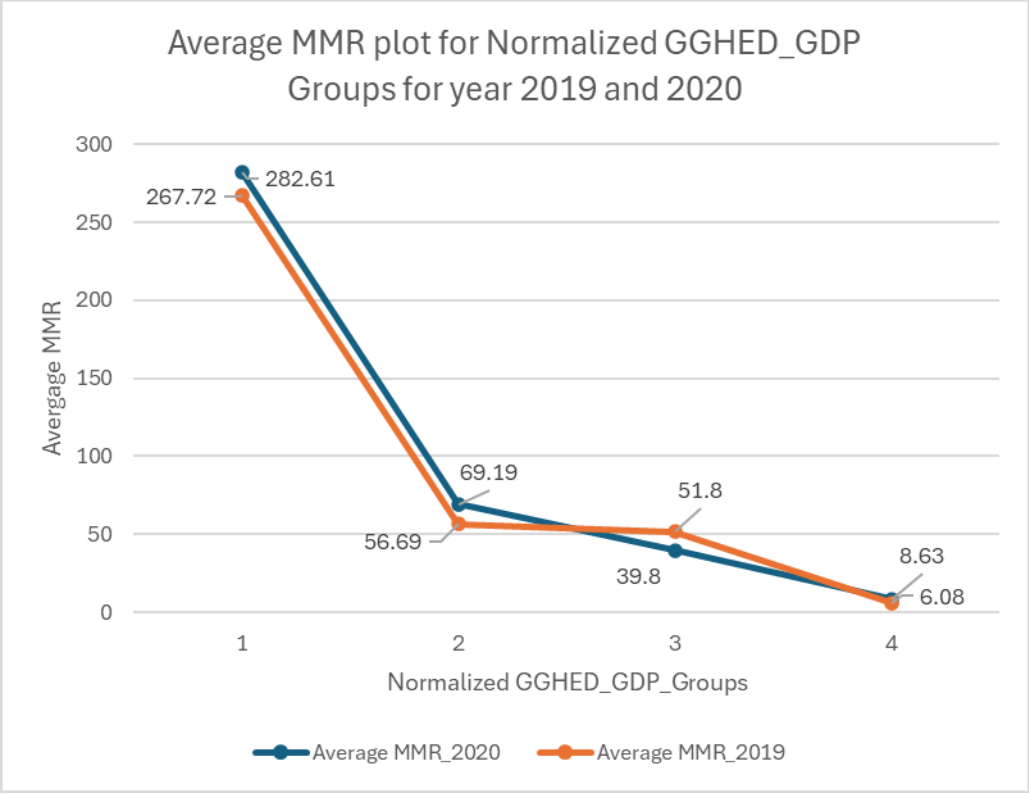
GGHED_GDP_Group	Average_MMR_2020	Count_2020	Average_Norm_LN_MMR_2020	Average_MMR_2019	Count_2019	Average_Norm_LN_MMR_2019
1	282.61	64	73.52	267.72	71	71.22
2	69.19	63	50.75	56.69	55	48.35
3	39.8	25	41.37	51.8	30	39.86
4	8.63	16	24.69	6.08	12	24.25

It can be observed that the group of countries with Higher GGHED_GDP has less impact on MMR compared to group of the countries with Lower GGHED_GDP group, where in lower group, MMR went up slightly from year 2019 to year 2020.

This effect can be visualized with the following graph.

Figure 6:

Difference in MMR between Year 2019 and 2020 by GGHED_GDP groups



The test of the comparison can be done with paired T-test if the data are almost normally distributed. However, if the data are not normally distributed, Wilcoxon Signed Ranking test is to be used.

To decide which hypothesis test to be performed, normality test is done on normalized LN_MMR value using SPSS.

Figure 7:

Normality test result on Normalized LN_MMR

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Norm_LN_MMR_2020	.075	144	.049	.968	144	.002

a. Lilliefors Significance Correction

Interpretation:

Null Hypothesis: The data is normally distributed.

Alternative Hypothesis: The data is not normally distributed.

Both tests have p-values of Kolmogorov-Smirnov Test and Shapiro-Wilk Test are less than 0.05. This means the null hypothesis is rejected and conclude that the data is not normally distributed. Therefore, the Wilcoxon Singed Ranking test is to be performed to analyze the difference of MMR for this Hypothesis.

Results

1. Is there a linear relationship between HDI and MMR?

To analyze the relationship between HDI and MMR, simple linear regression is performed between HDI and LN_MMR value for year 2018 to 2019. The result statistics of the linear regression are shown in the following table.

Table 6:

Linear Regression results statistics between Normalized HDI vs LN_MMR from year 2018 to 2020

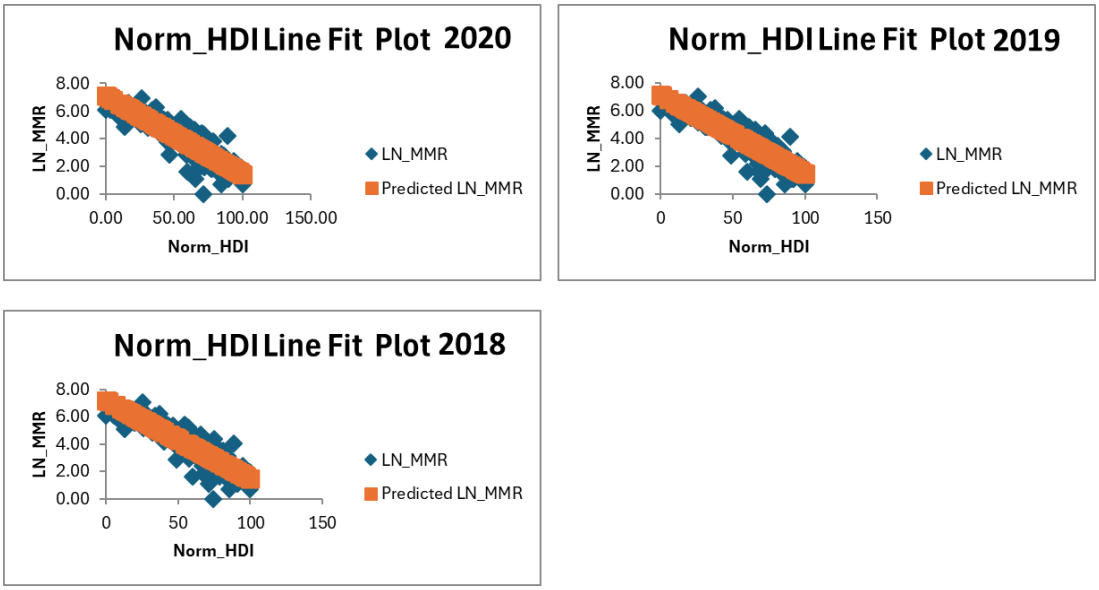
Metrix	2018	2019	2020
β_0	7.21	7.16	7.12
Coefficient of Norm_HDI(β_1)	-0.057	-0.056	-0.056
R-square	0.81	0.807	0.801
Model Equation	Y= 7.21- 0.057X	Y= 7.16- 0.056X	Y = 10.95-0.056X
P values	P<0.0001	P<0.0001	P<0.0001

- **Negative Relationship:** The regression models for all three years consistently show a negative relationship between the HDI and LN_MMR and it is statistically significant. This means that as HDI increases, the maternal mortality rate decreases.
- **Model Strength:** The R-squared values, which range from 0.807 to 0.895, indicate that the models explain a substantial portion of the variation in LN_MMR. This suggests that HDI is a strong predictor of maternal mortality rates.
- **Stability Over Time:** The coefficients for HDI have remained relatively stable across the years, indicating that the relationship between HDI and LN_MMR has not significantly changed over time.

Based on this result, Null Hypothesis (**H0: There is no direct linear relationship between HDI and LN_MMR)** is rejected and the alternative Hypothesis (**H1: There is a direct linear relationship between HDI and LN_MMR**) is accepted.

Figure 8:

LN_MMR vs Normalized HDI Line Fit Plot for 2018 to 2020



The scatter plots above displayed for the years 2018 to 2020 illustrate the negative linear relationship between the HDI and LN_MMR.

2. Is there a linear relationship between GGHED_GDP and MMR

A simple linear regression model was fitted for each year to quantify the relationship between GGHED_GDP and LN_MMR for the years 2018 to 2020. The result statistics of the linear regression are shown in the following table.

Table 7*:*

Linear Regression results statistics between Normalized GGHED_GDP vs LN_MMR from year 2018 to 2020

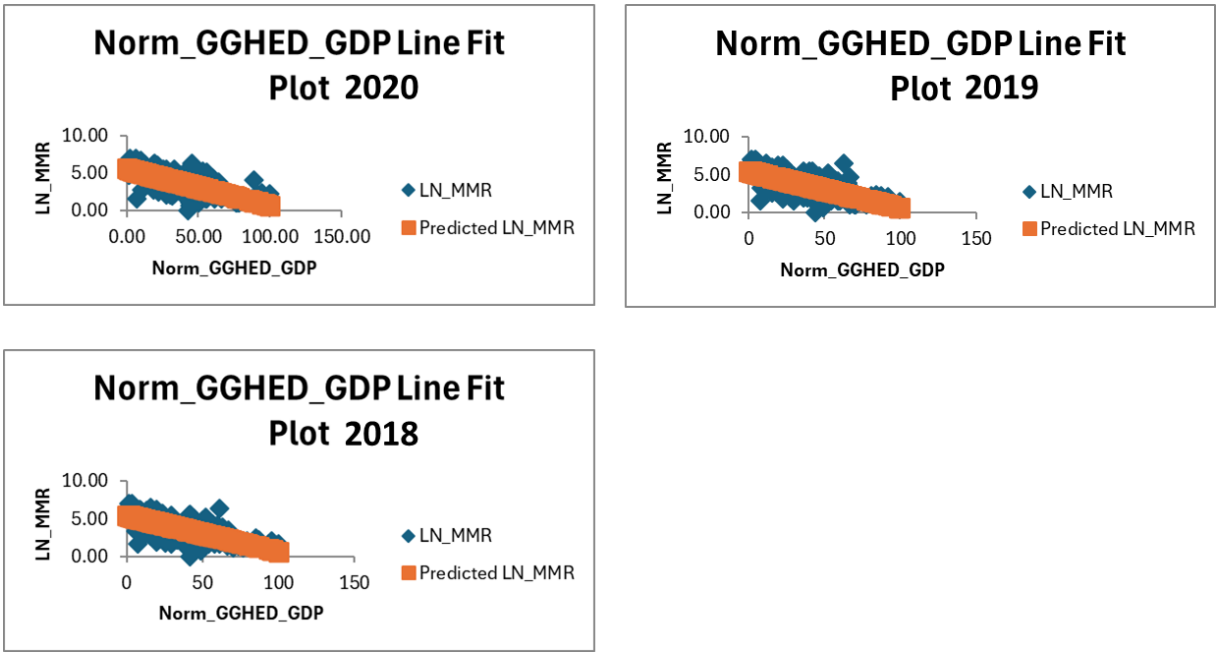
Metrix	2018	2019	2020
β_0	5.47	5.48	5.61
Coefficient of Norm GGHED_GDP(β_1)	-0.048	-0.048	-0.05
R-square	0.49	0.485	0.497
Model Equation	Y= 5.47- 0.048X	Y= 5.48- 0.048X	Y = 5.61-0.05X
P values	P<0.001	P<0.001	P<0.001

1. **Negative Relationship:** In all three years, the coefficient for normalized GGHED_GDP (β_1) is negative and p-value is less than 0.001. This indicates a negative relationship between government health expenditure and maternal mortality rate, and it is statistically significant. As government health expenditure increases, the maternal mortality rate tends to decrease.
2. **Model Strength:** The R-squared values vary across the years, but they all indicate that the models explain a moderate portion (nearly 50%) of the variation in LN_MMR. This suggests that GGHED_GDP is a considerable predictor of maternal mortality rates, but the coefficient of GGHED_GDP is small, which means other factors may also play a role.
3. **Stability of the Relationship:** While the magnitude of the coefficients for GGHED_GDP varies slightly across the years, the overall negative relationship remains consistent. This suggests that the impact of government health expenditure on maternal mortality has been relatively stable over time.

Based on this result, Null Hypothesis (**H0: There is no direct linear relationship between GGHED_GDP and LN_MMR**) is rejected and the alternative Hypothesis (**H1: There is a direct linear relationship between HDI and LN_MMR**) is accepted.

Figure 9:

LN_MMR vs Normalized GGHED_GDP Line Fit Plot for 2018 to 2020



3. Does GGHED_GDP act as Moderator in relationship between HDI and MMR?

To determine the impact of GGHED_GDP as moderator regression between normalized GGHED_GDP, normalized HDI, interaction terms (GGHED_GDP x HDI) and LN_MMR are performed to observe the significance of interaction term.

The following table are the results of the regression.

Figure 10:

Regression Statistics of Regression between normalized HDI, normalized GGHED_GDP and LN_MMR and interaction term between HDI and GGHED_GDP

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8972018
R Square	0.804971
Adjusted R Square	0.8014034
Standard Error	0.7329278
Observations	168

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regression	3	363.6196	121.206546	225.6335	5.66E-58
Residual	164	88.09805	0.53718321		
Total	167	451.7177			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	6.9570918	0.209379	33.2273273	9.63E-75	6.543666	7.370517123	6.543666	7.370517
Norm_HDI_2020	-0.0506219	0.004057	-12.478161	1.5E-25	-0.05863	-0.04261152	-0.05863	-0.04261
Norm_gghed_gdp_2020	0.0014485	0.008767	0.1652322	0.868965	-0.01586	0.018758679	-0.01586	0.018759
Norm_HDIxGGHED_2020	-9.365E-05	0.000105	-0.8896616	0.374951	-0.0003	0.000114198	-0.0003	0.000114

The following can be concluded from the result.

1. **Model Fit (R^2 and Adjusted R^2):**

- The model explains 80.4% of the variance in MMR ($R^2 = 0.804971$), which indicates good overall fit.
- Adjusted $R^2 = 0.801403$ shows the model remains robust even when adjusted for the number of predictors.

2. **Main Effects**

- **Norm_HDI_2020**: Highly significant (p = 1.5e-25), showing that HDI has a strong relationship with MMR.
- **Norm_gghed_gdp_2020**: Not significant (p = 0.869865), suggesting GGHED has no direct effect on MMR in this model.

3. **Interaction Term (Norm_HDIxGGHED_2020):**

- The interaction term is not statistically significant (p = 0.374951), meaning there's no evidence that GGHED moderates the relationship between HDI and MMR.

Figure 11:

Regression Fit plot between Interaction term and LN_MMR

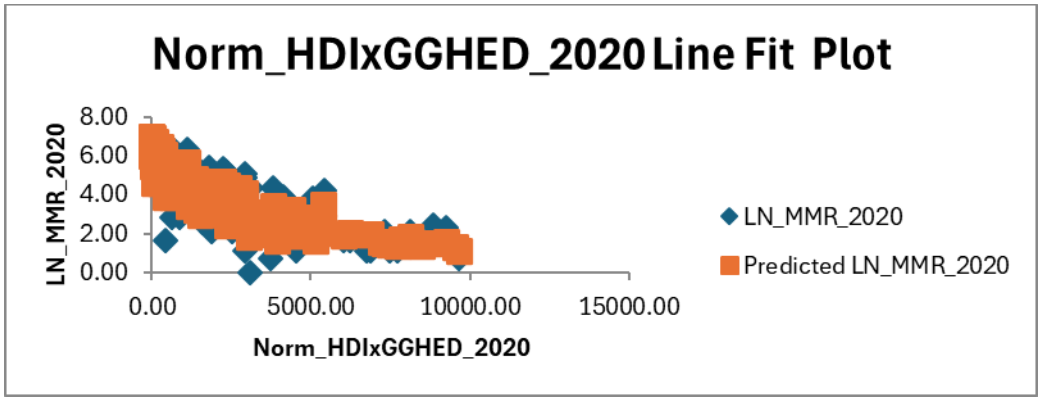


Figure 12:

Regression fits plot between normalized GGHED_GDP and LN_MMR

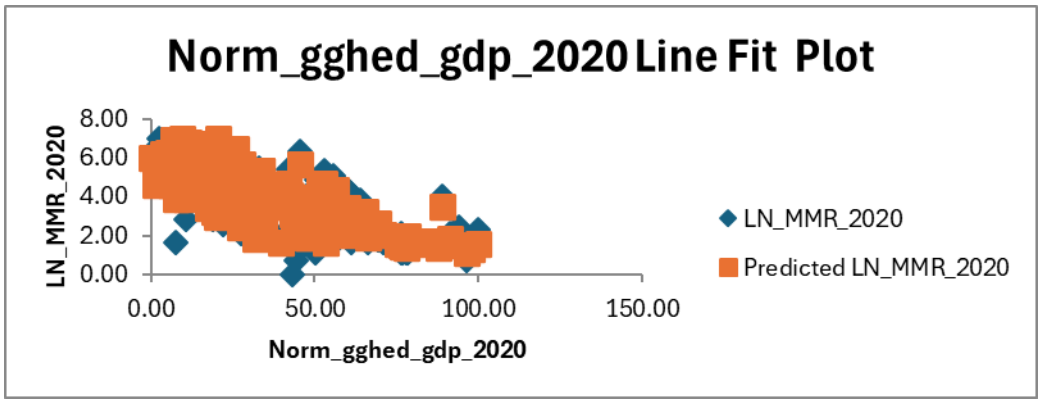
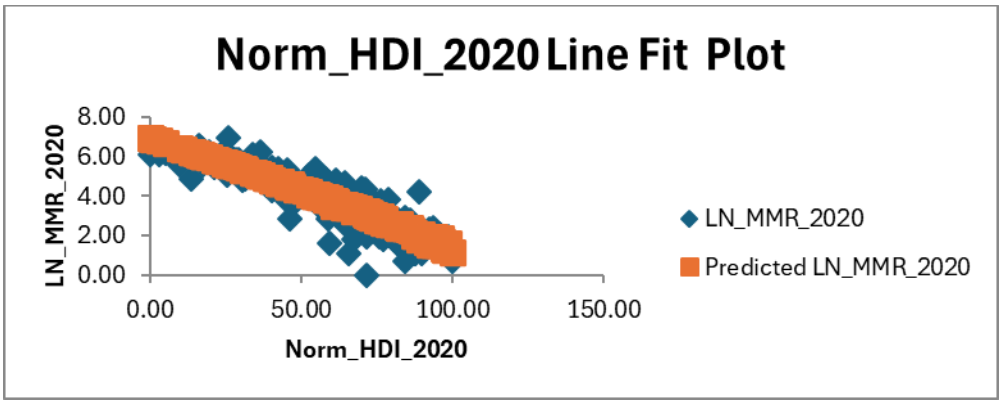


Figure 13:

Regression fits plot between normalized HDI and LN_MMR



Insights:

1. GGHED Fails as a Moderator:

- Based on this model, GGHED does not significantly influence the strength or direction of the relationship between HDI and MMR.

2. Possible Issues:

- Multicollinearity: If HDI and GGHED are highly correlated, it can reduce the significance of the interaction term even though VIF value is less than 2.
- Insufficient Variation in GGHED: If GGHED has limited variability or is concentrated around certain values, it may not show significant effects.

4. Does GGHED_GDP act as Moderator in relationship between HDI and MMR?

To analyze this statistically, Wilcoxon Signed Ranks Test is performed across the countries within the same group of GGHED_GDP. To simply and hold GGHED as constant, countries with different GGHED_GDP group rank are excluded from the test. Since the test is ranking MMR values between two countries, normalized LN_MMR is used to be more comparable and improve the performance.

Table 8:

Definition of Wilcoxon Signed Ranking

Negative Ranks	Norm_LN_MMR_2019 < Norm_LN_MMR_2020
Positive Ranks	Norm_LN_MMR_2019 > Norm_LN_MMR_2020
Ties	Norm_LN_MMR_2019 = Norm_LN_MMR_2020

Table 9:

Wilcoxon Singed Ranking test for Normalized LN_MMR values between 2019 and 2020 for individual GGHED_GDP group

GGHED_GPD Group	Negative Ranks N	Positive Ranks N	Ties N	Total N	Mean Negative Ranks	Mean Positive Ranks	Sum Negative Ranks	Sum Positive Ranks	Asymp Sig (2-tailed)	Monte Carlo Sig (2-tailed)
1	40	20	2	62	30.88	29.75	1235	595	**0.018**	**0.014**
2	37	11	1	49	26.08	19.18	965	211	**0**	**0**
3	18	3	0	21	10.78	12.33	197	37	**0.006**	**0**
4	10	2	0	12	5.6	11	56	22	**0.182**	**0.208**
Total	105	36	3	144						

Based on the results, Normalized LN MMR values in 2019 are lower than those in 2020 and statistically significant for lower GGHED_GDP groups based on both Asymptotic and Mote Carlo p-values. For GGHED_GDP group 4(LN_MMR score more than 75%), even though normalized LN MMR values in 2019 are lower than 2020 the values are insignificant.

From this result we can make the reject the null hypothesis which is **H0: Effect of pandemic on MMR is the same regardless of GGHED_GDP** and accept alternative hypothesis **H1: Effect of pandemic on MMR decreases as GGHED_GDP increases.**

Therefore, it can be concluded that increase in GGHED_GDP eases the effects of pandemic.

Discussion

Broader Implications of Findings

The analysis reveals a strong negative relationship between the Human Development Index (HDI) and maternal mortality rates (MMR), emphasizing the critical role of socioeconomic development in improving maternal health outcomes. Higher HDI levels, driven by better education, income, and life expectancy, consistently correlate with lower MMR. This finding highlights the importance of addressing disparities in socioeconomic conditions to achieve global health goals. This finding is further backed by the study made by Alimohamadi et al. (2018) demonstrating that improving that improving HDI might have a definite impact on decreasing MMR and U5MR, especially in low- and middle-income countries.

Government healthcare expenditure (GGHED) also plays a role in reducing MMR. Although its direct effect is significant based on simple linear regression between GGHED and MMR, the data does not support its moderating role between HDI and MMR in multi-linear regression. This suggests that while GGHED is essential for improving health outcomes, its impact may be constrained by factors such as healthcare quality or systemic inefficiencies.

During the pandemic, countries with higher GGHED exhibited smaller increases in MMR, underscoring the importance of healthcare funding in mitigating crisis impacts. This demonstrates the need for robust health systems to safeguard vulnerable populations during health emergencies.

Policy and Practice Implications

- These findings provide actionable insights for policymakers. Investments in socioeconomic development must be coupled with targeted healthcare spending to achieve sustainable improvements in maternal health.

- Regions with low HDI require comprehensive interventions that address systemic barriers such as poverty and limited access to education or healthcare.
- The results also suggest that governments should prioritize the resilience of healthcare systems, especially during crises, by maintaining and increasing health budgets.

Limitation and Challenges

The study faced several limitations.

- Excluding countries due to missing or extreme data reduced the sample's global representativeness, potentially affecting the findings' generalizability.
- Additionally, while multicollinearity between HDI and GGHED was addressed, its presence may have slightly dampened the interaction effect.
- Another limitation is the lack of detailed subnational data. Variations within countries such as healthcare access could provide deeper insights into local dynamics influencing maternal mortality.

Recommendation

Policy Recommendations

- Prioritize Socioeconomic Investments: Governments should focus on improving education and income levels, as these are key components of HDI that significantly impact maternal health.
- Enhance Healthcare Spending: Policymakers should allocate more resources to healthcare, particularly maternal health services, to directly address preventable maternal deaths.

- Strengthen Pandemic Preparedness: Develop strategies that integrate increased healthcare spending with emergency response plans to mitigate the impacts of future crises on maternal health.
- Localize Interventions: Design region-specific policies tailored to local HDI levels and healthcare system capabilities to maximize effectiveness.

Practical Applications

- Increase community awareness about the importance of maternal health and access to skilled birth attendants.
- Foster international collaborations to share successful strategies and allocate resources to high-needed regions.
- Develop tools and dashboards to help policymakers track HDI, GGHED, and MMR trends, enabling data-driven decisions.

Future Research Directions

- Improve Data Collection: Establish global standards for collecting data on socioeconomic and health indicators, ensuring consistency and comprehensiveness
- Future research should explore nonlinear relationships between HDI, GGHED, and MMR to uncover potential complexities in these interactions.
- Testing additional moderating or mediating variables, such as cultural factors or private healthcare spending, may also yield valuable insights.
- Control for confounding variables such as stability of the country, cultures
- Expanding the dataset to include subnational or longitudinal data could further enhance the understanding of maternal health disparities.

Conclusion

This study analyzed the impact of the Human Development Index (HDI) and Government Health Expenditure as a percentage of GDP (GGHED_GDP) on maternal mortality rates (MMR), with a focus on their interaction during global health crises. The findings confirmed a strong inverse relationship between HDI and MMR, emphasizing the critical role of socioeconomic development in reducing maternal mortality. While GGHED was found to have a direct negative effect on MMR, its role as a moderator in the HDI-MMR relationship was not statistically significant. However, higher GGHED levels helped mitigate the pandemic's adverse impact on maternal health outcomes.

The results underscore the need for comprehensive strategies that integrate socioeconomic improvements and robust healthcare funding to reduce maternal mortality. Policymakers are encouraged to prioritize investments in education and healthcare infrastructure, particularly in low-HDI regions, to achieve sustainable health improvements. The study also highlights the importance of building resilient healthcare systems to withstand health crises effectively.

Despite its contributions, the research faced limitations such as data constraints, exclusion of certain countries, and limited exploration of subnational variations. Future studies should consider addressing these limitations and exploring other potential moderators or nonlinear relationships to deepen our understanding of maternal health disparities.

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