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Estimating the Non-linear Impact of Environmental Degradation on Climate Vulnerability in Developed and Developing Economies: A Pathway to achieve Sustainable Development

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ABSTRACT

Climate change is a pressing issue in today's world and is discussed in national and international forums. Human activities are blamed as the primary forces behind environmental degradation and climate issues. This study assesses the role of environmental degradation on climate vulnerability from a global perspective. For this purpose, panel data of countries are collected from 1990 to 2023. The empirical results are estimated through panel quantile regression (PQR). Environmental degradation is measured using ecological footprint, and climate vulnerability is measured using the health vulnerability index by ND-GAIN. The empirical results proved the U-shaped relationship between ecological footprint and health vulnerability in different quantile groups. The further analysis explores that three developed countries (Luxembourg, Qatar, and the United Arab Emirates) have achieved the threshold value of the U-shaped curve and lay on the right side. In contrast, the remaining countries are located before maturity. The study warns that if these countries deplete the natural resources at the same speed, they push toward the right side of the U-shaped curve, which causes more health vulnerability. This study suggests that the governments of all global countries should pay special attention to the declining ecological footprint, which reduces climate vulnerability and improves the health sector.

Introduction

Most countries prioritize exploiting natural resource consumption to meet their population's demand. The relentless consumption of natural resources leads to far-reaching adverse impacts on our planet and impedes the achievement of sustainable development goals (SDGs). Although natural resource consumption is considered essential for powering economies, it badly damages our environment and causes climate vulnerabilities (Dhrifi, 2018; Ou et al., 2023). Researchers and policymakers blame environmental degradation for damaging the global climate (Asghar, Amjad, & Rehman, 2022; Sial et al., 2022; Iram et al., 2024; Ishfaq et al., 2024). It causes extreme weather events like floods, earthquakes, heat waves, and hurricanes that cause injuries, displacement, and loss of life (Weimin et al., 2022; Alimonti et al., 2022; Ebi et al., 2021; Huang et al., 2023; Ameet et al., 2024). Recognizing the importance of the impact of environmental degradation on climate vulnerability. COP27 (2022) discussed climate change issues and formulated different strategies to mitigate its adverse effects. Climatic-related extreme events badly damage all aspects of society all over the globe. Eckstein et al. (2021) estimated that extreme climatic events had killed nearly half a million people and caused a GDP loss of about 2.56 trillion in the last 20 years; developing countries bore more of the burden of it.

This research explores the role of environmental degradation on climate vulnerability. The researchers failed to determine the exact proxy to measure environmental degradation. In several studies, atmosphere pollution has been named environmental degradation using the proxy of carbon and greenhouse gas emissions (Sibt-e-Ali et al., 2023; Naiyer & Abbas, 2022; Rani et al., 2022b, 2022a). It is caused by hazardous waste contamination in the air, which badly destroys the ecosystem. Unlike the previous literature, this study measures environmental quality by using the ecological footprint (EFP) instead of greenhouse gases, CO_2 emissions, and other indicators (Ulucak & Bilgili, 2018). Wackernage and Rees (1997) introduced the concept of EFP to measure environmental degradation. The key reason behind developing this concept was the recognition of human activities greater than the earth, atmosphere, and water carrying capacity. It captures the overall impact of human activities in the environment based on natural resources, land use, waste generation, carbon emissions, and water use (Chen et al., 2022; Jhariya et al., 2021; Javaid et al., 2023). It offers a holistic view of sustainability compared to greenhouse gases, carbon emissions, deforestation, and water pollution indicators.

Additionally, vulnerability states the adverse emotional or physical effects of not having adaptive capacity. ND-GAIN (2022) encompasses three key aspects: adaptive capacity, sensitivity, and exposure components of water, food, ecosystem, governance, health, social preparation, human habitat, and infrastructure. Adaptive capacity relates to the capability of a community or system to effectively adapt and respond to the consequences of climate change. Sensitivity represents the degree to which a community, ecosystem, or sector is susceptible to harm or disruption caused by climate change. Exposure relates to the extent to which a community, region, or population is directly or indirectly exposed to the potential effect of climate variability, like increasing temperatures, harsh weather events, or sea-level rise. The increase in global temperature caused by abrupt climate changes gives rise to diverse severe incidents, including deluge, earthquakes, and recurrent heat waves. The heightened harshness of intense events directly contributes to an increased loss of human lives (Dai et al., 2022).

Climate vulnerability is measured through different proxies like infrastructure, ecosystem, water, food, habitat, and health sector (ND-GAIN ,2022). This study uses the health vulnerability index (HVI) to examine the climate vulnerability. The HVI illustrates the disastrous effect of climate change on human health in terms of adaptive capacity, exposure, and sensitivity components (Clark & Preto, 2018). Fuller et al. (2022) discussed that more than nine million infant deaths are due to atmospheric corrosion. These deaths are more than from tuberculosis, AIDs, and malaria. Addressing HVI is critical to fostering health equity and enhancing population health (Chen et al., 2015).

Environmental contamination has a substantial influence on human health. Excessive contamination of the environment harms human health (Pata et al., 2021). Industrial and transportation contribute to air pollution, which promotes respiratory and cardiovascular disorders. Water contamination from industrial waste and chemical runoff causes infections and long-term health issues (Daripa et al., 2023; Siddiqua et al., 2022). Natural habitat destruction causes biodiversity loss, disturbs ecological equilibrium and may lead to new illnesses. It also increases the frequency and severity of heatwaves, storms, and droughts, which cause bodily suffering, spread illnesses and put a burden on healthcare systems (Sullenbarger et al., 2022).

This research sets a key objective: to investigate the role of environmental degradation on climate vulnerability. This research is significant because it uses the role of environmental pollution on the climate vulnerability of ND-GAIN (2022), while the previous studies use the different proxies of climate change like temperature, extreme events etc. This study measures climate change in a broader way using the adaptive capacity, sensitivity, and exposure components of water, food, ecosystem, governance, health, social preparation, human habitat, and infrastructure.

Literature Review

This section discloses the previous literature investigating the link between environmental degradation and climate vulnerability. No any previous literature explored the suitable proxy of environmental degradation. It is a challenging and difficult task to detect a suitable proxy. Several researchers used the ecological footprint (EFP) to measure environmental degradation (Amjad et al., 2023; Amjad & Rehman, 2023; Aslam et al., 2023; Hassan et al., 2019). However, few scholars have criticized the concept of EFP, as Fiala (2008) criticized the assumptions of estimating the EFP, assuming zero greenhouse gas (GHG). It explored that it makes it more challenging to extrapolate the EFP. Long et al. (2020) also criticized the usual EFP index and estimated the Ecological Well-being Performance (EWP) index by combining the EFP and HDI. This section connects environmental degradation with climate vulnerability. Previous literature indicates that the degradation of the environment affects climate through the direct outcomes of hazards such as heat waves, floods, storms, etc. To investigate the severe impact of environmental degradation on climate, most studies used different proxies to measure climate, like heat, temperature, and extreme events.

There are only few research works that evaluate HVI besides climate change. Birkmann et al. (2022) worked on exploring vulnerability dimension. The research examined that climate change-induced disasters wreaked havoc regarding death toll 15 times higher in higher vulnerable countries than in lower-ranked countries. Apart from these studies, several studies connect the environmental degradation indicator with health outcomes. Biyase et al. (2023) investigated that ecological footprint (EFP) positively affected life expectancy and declined mortality in E7 countries. Uddin et al. (2023) determined that the EFP increased population growth and birth rate while reducing life expectancy. Rajput et al. (2023) studied the different aspects of climate factors in the health sector in India. The study overviewed that climate-resilient approaches transformed health development.

Several studies carried out the role of environmental degradation on infant mortality rates. Strukcinskiene et al. (2023) investigated the effect of industrial total particle pollution (TPP) on children's morality in Europe in under one year. The study evaluated that TPP spreads different respiratory diseases in children aged less than one who face more risk of health. Climatic events such as hurricanes, floods, and heatwaves directly adversely impact human health through displacement, injuries, and fatalities. These events also indirectly affect human health by spreading infectious diseases, mental health issues, loss of infrastructure, and food and water shortages. Rajput et al. (2023) studied the different aspects of climate change on human health in India. This study used the gridded map of the vulnerable population to understand the adverse impacts of climate on human health. The study overviewed that climate-resilient approaches transformed health development. Wang et al. (2023) found that PM2.5 concentration in air pollution caused 163 infant mortality per 100,000 births. Lee et al. (2023) determined heat exposure caused mortality rates due to mental illness, infections, suicide, hospitalization, and violence.

Akanwa et al. (2023) highlighted the consequences of climatic factors and repeated flood events that damaged the infrastructure, land, and roads. Water flooding increases the breeding of mosquitoes that cause malarial diseases and respiratory infections. Silveira et al. (2023) studied that heatwaves increased the risk of mortality. Furthermore, this study also pointed out that women and older people were vulnerable to heat waves. Kumar et al. (2023) explored that overexploitation of resources by overpopulation and global competitiveness drastically declines the biocapacity of the earth, which ultimately leads to higher EFP. Amjad (2023a) explored the U-shaped relationship with GHG and HVI.

Several studies examined that globalization declines health vulnerability. There is no any previous study that directly connects globalization with health vulnerability. However, several studies connect globalization with health outcomes. Farooq et al. (2019) revealed that globalization increased life expectancy. Panda (2020) scrutinized that an increase in globalization leads to improved health outcomes. Shah et al. (2021) discovered that an upsurge in globalization leads to a raise in health status. Hamdi and Hakimi (2021) showed that globalization significantly increased human development. Kojo-Ayesu et al. (2022) concluded that globalization directly increased human welfare.

There are also many studies that explore the damage caused by globalization to health outcomes. Jawadi et al. (2018) inspected that globalization has increased infant mortality. Ibrahim and Sare (2018) scrutinized globalization as adversely affecting human health. Ullah et al. (2019) inspected that globalization increased healthcare expenditures. Bombardini & Li (2020) explored that globalization increased the infant mortality rate.

Urbanization got special importance in studying human health because most health facilities exist in urban areas in developing countries. Urbanization has both positive and negative influences on health outcomes. Ely et al. (2017) examined that the infant mortality rate has diminished due to urbanization in the US economy. Bandyopadhyay and Green (2018) investigated a negative link between the urban population and mortality rate. Jiang et al. (2021) highlighted that Urbanization declined the deaths rate at higher GDP per capita threshold. Tripathi and Maiti (2023) found that Urbanization declined the fertility rate and increased life expectancy. Sun et al. (2023) assessed that urbanization improves human health through proper medical facilities while, on the other hand, it adversely damages humans through environmental pollution.

Urbanization may also adversely damage the health sector due to higher environmental degradation. Sastry (2004) accompanied his study in Brazil from 1971 to 19, exposing the association between urbanization and infant mortality rate. The study explored that urbanization increased the mortality rate due to higher pollution.

Industrialization has observed a mixed effect on human health. Barenberg et al. (2016) scrutinized the inverse association between industrialization and the infant mortality rate. Dhrifi (2018) explored that industrialization diminished the infant mortality rate. Dong et al. (2021) examined the impact of urbanization and industrialization on health concerns. The research revealed that industrialization adversely impacted health concerns.

There are also few studies that explore that industrialization badly. Makaranga et al. (2019) observed the influence of industrialization and the growth process on health in Tanzania. The study demonstrated that industrialization increased the infant mortality rate. Rahman et al. (2021) scrutinized the negative association between industrialization and health conditions. Ludlow and Hackett (2019) empirically found that industrialization increased health inequalities. Tavassoli et al. (2020) showed that industries caused environmental pollution that increased infant mortality.

Upon examining the literature, it is evident that several literatures examine the role of environmental degradation on climate vulnerability using different proxies like extreme events and temperature degradation (Aşici & Acar, 2016; Figge et al., 2017; Hassan et al., 2019). This study measures the climate vulnerability using ND-GAIN proxy of HVI. There is limited literature that explored the non-linear association of environmental degradation on HVI. However, numerous literatures capture the impact of environmental degradation on different health indicators like deaths rate and life expectancy (Birkmann et al., 2022; Barua et al., 2022; Biyase et al., 2023; Long et al., 2020; Strukcinskiene et al., 2023).

Data and Methodology

To achieve the objective of investigating the role of the environment on climate vulnerability, panel data from 97 developed and 62 developing countries were collected from 1990 to 2023. The environmental degradation is measured through the ecological footprint index (EFP) and serve as the explained variable. Furthermore, climate vulnerability is measured by using health vulnerability (HVI). HVI measures different health variables. Its index value ranges between 0 and 1. Lower HVI means lower health vulnerabilities and higher HVI means higher health vulnerabilities. For simplicity, this study converts HVI values into 0 and 100. In this study, EFP used as the non-linear behavior to determine the HVI (Figure 2). It shows the U-shaped relationship which lower value of EFP declines HVI and higher EFP increases HVI. Further details of the concern variables are discussed in Table 1.

Table 1: Description of the Variables

Symbol	Indicator	Units	Sources
HVI	Health Vulnerability	Index (1 to 100)	ND-GAIN (2024)
EFP	Ecological footprint	Gha per person	GFN, 2024
KOF	Globalization	Index	WDI (2024b)
URP	Urbanization	% of total	WDI (2024b)
IND	Industry value added	% of GDP	WDI (2024b)

To empirically examine the long-run dynamics of the EFP on HVI, this study uses EFP as the independent variable, while health vulnerability is the dependent variable. It is observed that EFP behave in non-linear trend lines like the U-shaped relationship. Explain the reasons/ justification and mechanism behind the non-linear impact.

So, it uses the quadratic EFP term to determine health vulnerability.

$$HVI=f(EFP, EFP^2, KOF, LNURP, LNIND) \qquad (1)$$

Multiple regression can be expressed using equation (1) as

$$HVI_{it} = \delta_0 + \delta_1(EFP)_{it} + \delta_2(EFP)^2_{it} + \delta_3(LNKOF)_{it} + \delta_4(LNURP)_{it} + \delta_5(LNIND)_{it} + (\varepsilon)_{it} \quad (2)$$

In equation (2), δ_1 shows the coefficient of EFP and δ_2 displays the coefficient of quadratic EFP. To examine the threshold value, 1st derivative to the EFP of equation (2) can be used as:

$$FFP^*_{it} = -\frac{\delta_1}{2\delta_2} \quad (3)$$

Equation (3) displays the threshold value of the non-linear curve.

In this study, we employ panel quantile regression (PQR). It is particularly useful for capturing the heterogeneous effects of environmental degradation across different quantiles of climate vulnerability, providing a more nuanced understanding of the non-linear dynamics. To ensure robustness of the results, we apply the method of moments quantile regression (MM-QR), which offers a more efficient and reliable estimation of parameters under varying distributional assumptions. This dual approach allows us to explore how the effects differ across the vulnerability spectrum while confirming the robustness of our findings through a rigorous methodological framework.

Results and Discussions

Tables 2 demonstrate the descriptive statistics of the developed and developing countries. The mean value of HVI (36.86) in developed countries is less than the mean value of HVI (62.97) in developed countries. It shows that developing countries are facing more health vulnerabilities than developed countries as average HVI is almost doubled i.e., about 62.98 in case of developing economies as compared to 36.87 in developed countries.

Table 2: Descriptive Statistics

		Developed Countries			
Variable	**Obs**	**Mean**	**Std. dev.**	**Min**	**Max**
HVI	3,298	36.8677	11.3376	-20.3761	66.1774
EFP	2,890	4.3536	2.6673	-4.6903	18.0719
KOF	3,230	63.5915	15.2610	19.9189	91.1372
LNURP	3,298	14.9361	2.3367	8.2250	20.6290
LNIND	3,272	3.2708	0.4402	-0.9444	4.6888
		Developing Countries			
HVI	2,108	62.9760	13.3483	0.0000	87.6731
EFP	2,006	1.4553	0.8762	-3.4295	10.6394
KOF	2,006	43.8531	11.1038	11.9816	74.5488
LNURP	2,108	15.0156	1.7333	10.2484	20.0693
LNIND	2,088	3.0531	0.4987	-1.8006	4.2866

The ecological footprint index (EFP) is considered the key independent variable. The mean value of EFP (4.35) of developed countries is greater than the mean value of EFP (1.45) of developing countries, showing that a person is consuming more natural resources (i.e. on average 4.35 Gha per person as per EFP value in developed countries, i.e., almost three times larger than a person consumption living in the developing economics (Amjad et al., 2021a; Amjad, Rehman, et al., 2022).

Figure 1 show the correlation plot which is traced by using original value of correlation matrix in R-language software. The diagonal dark blue square shows the perfect correlation of each variable with its own. In contrast, the remaining light blue and red squares show a small correlation values, which shows the weak multicollinearity issue (Sial et al., 2022).

Figure 1: Correlation plot

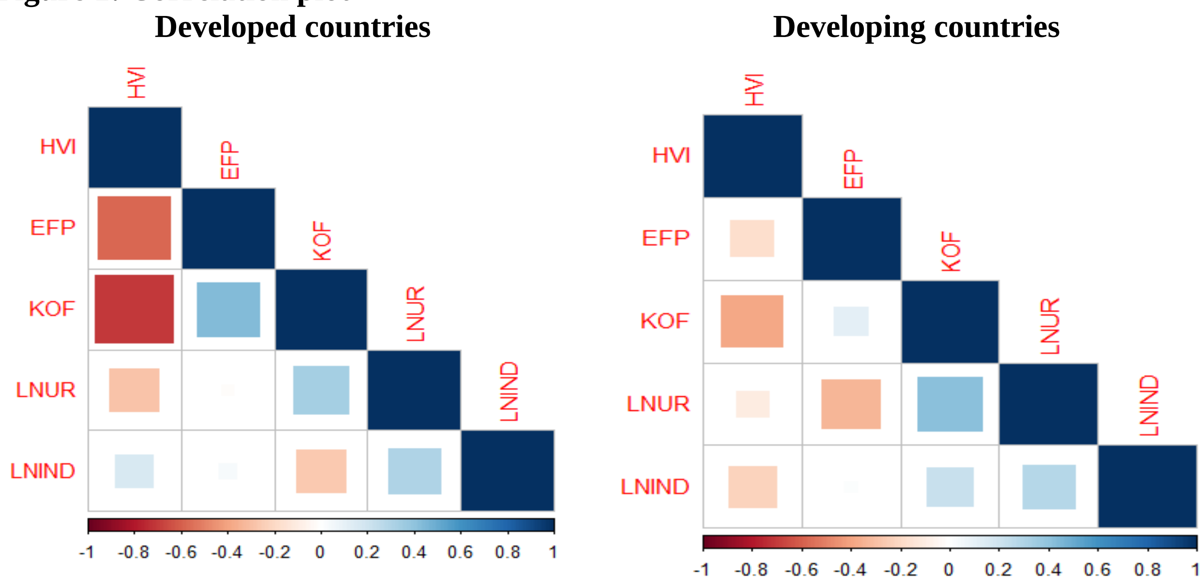


Table 3 presents the VIF of developed and developing countries. The mean value of VIF of developed countries is 1.56, and developing countries is 1.31, which is less than ten, showing the weak multicollinearity issue in both models (Abid et al., 2022; Amjad et al., 2021b; Amjad, Rafiq, et al., 2022).

Table 3: Variance Inflation Factor Results

	Developed countries		Developing countries	
Variable	**VIF**	**1/VIF**	**VIF**	**1/VIF**
EFP	1.4	0.7141	1.24	0.8046
KOF	1.88	0.5306	1.33	0.7534
LNURP	1.51	0.6634	1.55	0.6432
LNIND	1.44	0.6954	1.12	0.8957
Mean VIF	1.56		1.31	

To check the normality of the model, the Shapiro-Wilk test is used. Its null hypothesis is that the sample is normally distributed. It is estimated by using the covariance matrix of the sample and regression coefficients on the corresponding expected normal scores (González-Estrada et al., 2022). Table 4 shows the results of the Shapiro-Wilk test of developed and developing countries. The significant probability values indicate that both models are not normally distributed.

Table 4: Normality Test

	Developed Countries		Developing countries	
Variable	**W**	**W'**	**W**	**W'**
HVI	0.9787	0.9786	0.9633	0.9633
EFP	0.8980	0.8977	0.7071	0.7049
KOF	0.9750	0.9754	0.9926	0.9930
LNURP	0.9771	0.9774	0.9736	0.9739
LNIND	0.9661	0.9652	0.9129	0.9118

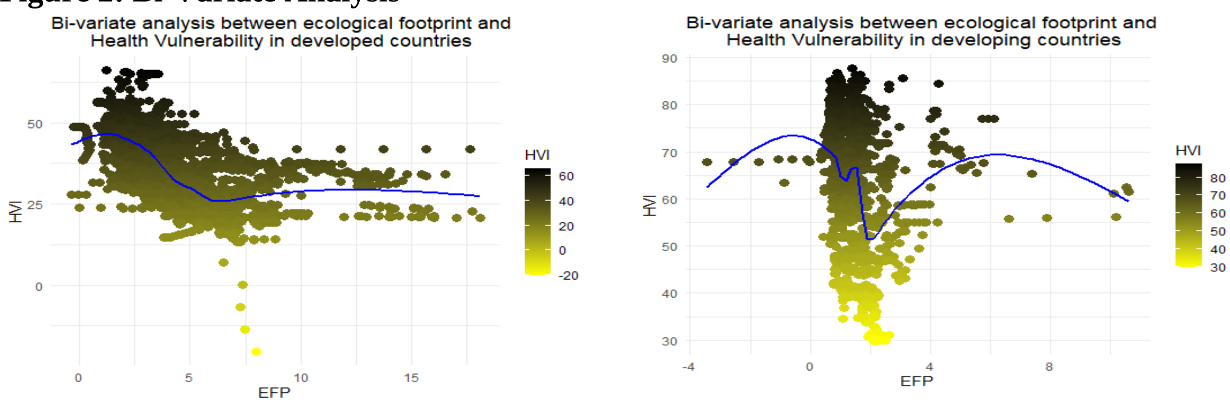
The Pesaran (2004) CD test is provided in Table 5. This test is crucial in this study since all nations are connected by a variety of geographical and economic characteristics. The p-values of all CD tests are significant, indicating that the null hypothesis is rejected and that the model has cross-sectional dependency.

Table 5: Cross-sectional Dependency Test

	Developed Countries		Developing Countries	
Variable	**CD-test**	**p-value**	**CD-test**	**p-value**
HVI	207.2100	0.0000	160.0000	0.0000
EFP	191.1100	0.0000	130.2900	0.0000
KOF	202.4500	0.0000	162.7200	0.0000
LNURP	215.9600	0.0000	176.6900	0.0000
LNIND	184.8800	0.0000	109.6000	0.0000

Figure 2 shows the bivariate analysis between EFP and HVI. The scatter plot presents the different points of the specific country of the values of EFP and HVI. It is observed that EFP and HVI show non-linear trend lines in developed and developing countries.

Figure 2: Bi-Variate Analysis



Panel unit root tests are statistical approaches for determining the stationarity of the variable in panel data. Stationarity refers to a situation where mean and variance remains constant over time (Beenstock & Felsenstein, 2019). In the context of EFP and HVI, a panel unit root test helps to check whether the variables are stationary or non-stationary. Table 6 presents the panel unit root test by using Levin, Lin & Chu (LCC), Im, Pesarsan, and Shin (IPS), Augmented Dickey-fuller test (ADF), and PP test. All panel unit root tests show except for LNIND, all variables become stationary at level (Asghar, Amjad, Rehman, et al., 2022; Asghar, Amjad, Ur Rehman, et al., 2023; Aslam et al., 2024; Rafique et al., 2023).

Table 6: Panel Unit Root Test

	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
				Level				
HVI	-21.623*	-28.048*	1136.32*	2193.6*	-10.996*	-13.562*	286.475*	289.691*
EFP	-11.752*	-19.746*	788.52*	1792.45*	-8.715*	-12.479*	254.629*	262.271*
KOF	-20.106*	-27.518*	1114.68*	1972.940*	-6.236*	-8.090*	182.735*	179.678*
LNUR	-22.394*	-25.707*	1028.22*	1974.61*	-4.013*	-7.298*	173.20*	171.42*
LNIND	-0.037	14.056	52.292	85.356	4.5470	11.4358	25.5805	26.9777
				1st difference				
HVI	-41.047*	-55.208*	2354.31*	2318.7*	-44.735*	-42.661*	863.099*	876.161*
EFP	-22.219*	-36.882*	1504.40*	4269.41*	-43.165*	-42.681*	742.10*	669.68*
KOF	-39.671*	-54.595*	2299.65*	2596.29*	-46.805*	-44.132*	817.44*	749.34*
LNUR	-41.768*	-54.107*	2314.64*	2192.72*	-46.71*	-44.147*	856.52*	813.64*
LNIND	-22.177*	-28.857*	1157.56*	2072.14*	-11.784*	-13.898*	309.375*	309.589*

*Note. * shows the level of significance at 1%*

Due to the presence of CD in this study, the 1st generation unit root tests lead to non-reliable and biased results. In such case, the 2nd generation panel unit root tests CIPS and CADF provide robust results in the presence of CD (Aouini et al., 2023; Pesaran, 2015). Table 7 displays the empirical results of CIPS and CADF tests at the level and first difference. The overall outcome shows that variables become stationary at the level at 1% level of significance (Abid et al., 2024; Amjad, 2023b; Asghar, Amjad, & Rehman, 2023).

The empirical results are estimated using panel quantile regression (PQR) at 25%, 50%, and 75% quantiles. Table 8 shows the PQR results of both samples. In developed countries, the linear coefficient of EFP is negative and its quadratic coefficients are positive, showing that higher EFP increases HVI (Biyase et al., 2023; Strukcinskiene et al., 2023; Abbas et al., 2023; Akanwa et al., 2023). In the case of developing countries, the lower EFP is negative and statistically significant in all quantile groups, showing the lower EFP decline HVI. The quadratic coefficient of EFP is positive and shows a higher EFP increase HVI (Gillani et al., 2021; Qaiser et al. 2021; Yang et al., 2021; Wang et al., 2023; Lee et al., 2023). The level of negative coefficients and positive quadratic coefficients of EFP proposes the U-shaped relationship in lower and higher quantile groups. This suggests that increasing levels of EFP contribute to environmental damage and climate change. Climate change causes extreme events that harm the health of the populace in underdeveloped countries.

Table 7: 2nd Generation Panel Unit Root Test

	Developed countries		Developing countries	
	CIPS	**CADF**	**CIPS**	**CADF**
		At level		
HVI	-6.190*	-5.758*	-6.190*	-6.059*
EFP	-3.563	-5.921*	-4.468**	-5.696*
KOF	-3.784	-6.110*	-6.190*	-6.136*
LNUR	-6.190*	-15.274*	-6.190*	-5.966*
LNIND	-5.356*	-2.146	-3.245	-21.365*
		1st difference		
HVI	-6.190*	-6.190*	-6.190*	-6.190*
EFP	-5.837**	-6.185*	-7.478*	-6.190*
KOF	-5.865*	-6.190*	-6.190*	-6.146*
LNUR	-5.234*	-26.628**	-6.190*	-6.190*
LNIND	-6.3445*	-26.728*	-6.308*	-26.638*

Note: p<0.01, ** p<0.05, *** p<0.1*

The lower part of Table 8 displays the quadratic coefficient cut-off values. The cut-off value represents the minimum value of the U-shaped curve. Dawson (2014) traced the relationship on the Excel sheet using the level and quadratic coefficients. Figures 3 and 4 provide the visual representation of the quadratic effect of EFP. It is traced by using the level and quadratic coefficient of EFP, mean value and standard deviation of EFP, and constant term of the complete model. Analyzing these variables shows the U-shaped relationship presented.

Table 8: PQR Results

	Developed countries			Developing countries		
	$\tau = 25^{th}$	$\tau = 50^{th}$	$\tau = 75^{th}$	$\tau = 25^{th}$	$\tau = 50^{th}$	$\tau = 75^{th}$
EFP	-4.1681*	-3.7134*	-3.6826*	-3.3393*	-1.9775**	-5.4461*
	(0.2496)	(0.1430)	(0.1779)	(1.0113)	(0.7944)	(0.7530)
EFP^2	0.1948*	0.1724*	0.1602*	0.3434**	0.1641	0.6488*
	(0.0172)	(0.0098)	(0.0122)	(0.1363)	(0.1070)	(0.1015)
KOF	-0.2058*	-0.3411*	-0.3782*	-0.4786*	-0.5524*	-0.3886*
	(0.0194)	(0.0111)	(0.0138)	(0.0441)	(0.0346)	(0.0328)
LNUR	-1.2531*	-0.4588*	-0.4754*	1.4028*	0.6531*	0.1071
	(0.1212)	(0.0695)	(0.0864)	(0.2996)	(0.2353)	(0.2231)
LNIND	3.7887*	3.2748*	2.7453*	-5.0235*	-3.5483*	-3.3450*
	(0.6077)	(0.3482)	(0.4331)	(0.9041)	(0.7102)	(0.6732)
Constant	64.8535*	66.3349*	74.8337*	75.5092*	92.4700*	103.5861*
	(2.2462)	(1.2872)	(1.6010)	(4.4337)	(3.4826)	(3.3012)
Pseudo R2	0.406	0.4823	0.4646	0.1310	0.1248	0.0976
Obs	2,874	2,874	2,874	1924	1924	1924
Cut-off value	10.69614	10.77065	11.4913	4.8626	6.0252	4.1969

*Note. *,**, *** presents level of significant at 1%, 5%, and 10%, respectively, () shows standard error*

The linearized marginal effect indicates that Luxembourg, Qatar, and the United Arab Emirates are located after the threshold value of the U-shaped curve. It also shows most developed countries still lie on the left side of the U-shaped curve, which declines the HVI. Only a few countries achieved the threshold value and moved to the positive side of the U-shaped curve. It is a very alarming situation for developed countries if they continue to deplete the natural resources at the same speed they push toward the right side of the U-shaped curve, which causes more health vulnerability. This situation is a curse because the developed countries have advanced health systems and resources, creating a false sense of security. Neglecting sustainable practices eventually undermines the health gains made possible by medical technology and healthcare infrastructure advances.

Figure 3: Quadratic Effect of EFP in Developed Countries

(a) (b) (c)

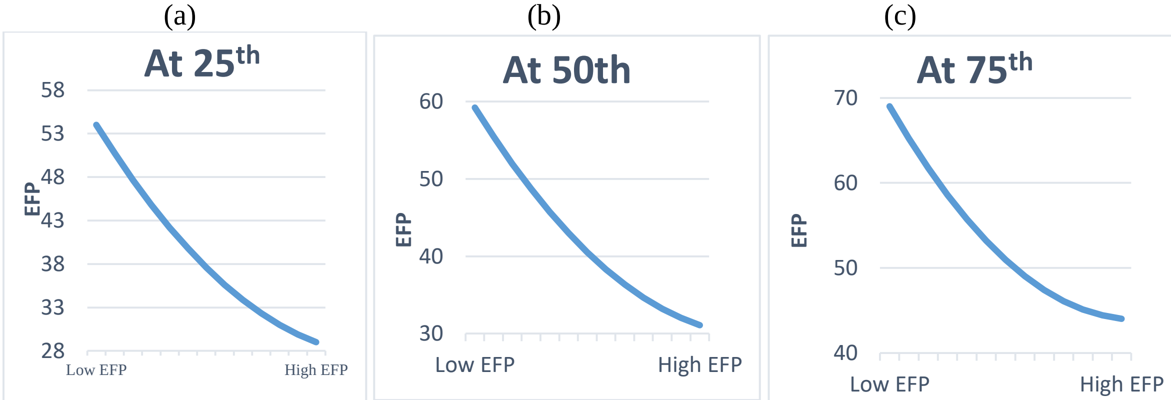
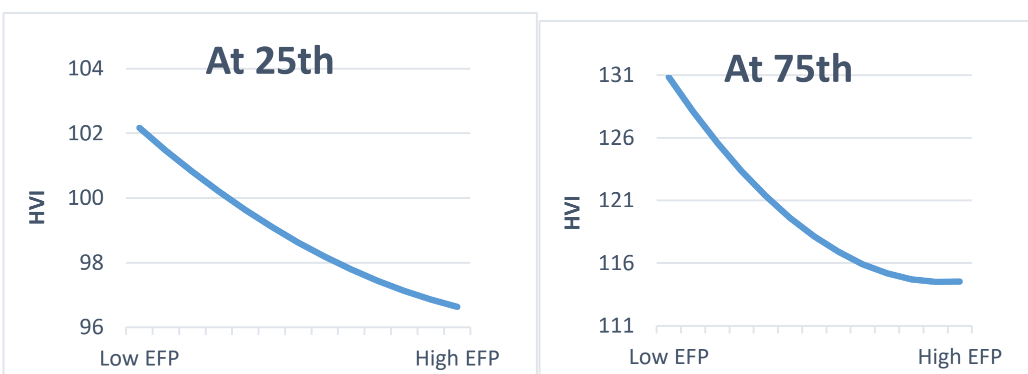


Figure 4: Quadratic Effect of EFP In Developing Countries

(a) (b)



The linearized marginal effect of 62 developing countries in lower and higher quantile groups. It indicates that all countries are laid before the maturity stage. Before the maturity stage, an inverse relationship exists between EFP and HVI. It is a critical situation for developing countries because they are increasing their consumption of natural resources to achieve higher Economic Development targets. For this purpose, the demand for energy, water, and minerals increased, rapidly increasing the EFP in these countries. The rising EFP exacerbates climate change and badly damages the healthcare sector (Note. Linearized marginal effect estimation is not presented due to space constraints.

This study includes a few control factors in addition to these major variables. Globalization (KOF) adversely impacts the HVI (Panda, 2020; Byaro et al., 2021; Kojo Ayesu et al., 2020). Increased globalization increases income and foreign exchange through improved healthcare infrastructure, medical facilities, and access to quality healthcare services. Furthermore, export-oriented industries invest in employee well-being by offering improved working conditions, healthcare benefits, and occupational safety measures (Asghar et al., 2024). Additionally, export-led Economic Development lowers poverty rates, reduces financial obstacles to healthcare access, and improves overall population health. Foreign money inflows and information exchange linked with exports also lead to advances in medical research, technical innovation, and new healthcare solutions, improving human health outcomes.

Urbanization (LNUR) has mixed effects on HVI. In developed countries, LNUR negatively impacts HVI in all quantile groups (Kuddus et al., 2020). In contrast, in developing countries LNUR positively impacts the HVI in lower and middle quantile groups. In developed countries urbanization plays a crucial role in improving the health sector. Usually, urban areas have better access to healthcare services than rural areas. Furthermore, urban areas are accompanied by improved infrastructure, such as enhanced sanitation, clean water supply, and waste management. These elements contribute to a healthier living environment by lowering the risk of waterborne infections and increasing public health overall.

Industrialization (LNIND) has mixed effects across each group. In developed countries, the HVI in all quantile groups increases (Tavassoli et al., 2020). Most developed countries' industrial sectors are based on polluted energy resources, which badly damage the environment. Higher air pollution levels lead to respiratory issues, cardiovascular disease, and other health concerns. Furthermore, occupational health and safety requirements may not be sufficiently implemented, resulting in work-related injuries, hazardous material exposure, and long-term health difficulties for workers. Industrialization also contributes to water and soil contamination, risking public health by consuming tainted water and food. Noise pollution from industrial activities and vehicles harms mental health and well-being.

In developing countries, industrialization (LNIND) declines HVI in all quantile groups (Asghar et al., 2022). Developing countries with a smaller industrial sector frequently emit less pollution than developed countries. Most of these countries have based on an agricultural and service-based economy, resulting in lower pollution. Lower pollution contributes to a cleaner environment, which positively impacts public health. It also reduces the risk of respiratory disorders, cardiovascular diseases, and other health problems caused by air pollution.

The robustness of the PQR approach is further validated through the application of the Method of Moments Quantile Regression (MM-QR) technique. This method examines the relationship between EFP and HVI across various quantile groups, including location, scale, and the lower, middle, and upper quantiles. The results indicate that the linear coefficient of EFP consistently has a negative effect on HVI across all quantiles, signifying that as environmental footprints increase, HVI initially decreases. However, the quadratic coefficient of EFP shows a positive impact across all quantile groups, implying that beyond a certain point, further increases in environmental footprint result in a rise in HVI. This finding demonstrates a U-shaped relationship between EFP and HVI. Importantly, these results align with the findings of the PQR approach, thereby confirming that the relationship between EFP and HVI is robust across different quantile estimation techniques. The consistency of the results across both methods suggests that the U-shaped relationship holds true irrespective of the specific quantile-based method used, reinforcing the reliability of the analysis.

Table 10: Results of MM-QR Approach

Dependent Variable: Ecological Footprint					
Developed Countries					
Variables	**Location parameters**	**Scale parameters**	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
EFP	-3.8295*	0.3775*	-4.1416*	-3.7821*	-3.4938*
	(0.2353)	(0.1199)	(0.2191)	(0.1459)	(0.1728)
EFP^2	0.1821*	-0.0202*	0.1988*	0.1796*	0.1641*
	(0.0137)	(0.0067)	(0.0130)	(0.0087)	(0.0103)
KOF	-0.3572*	-0.1224*	-0.2560*	-0.3726*	-0.4661*
	(0.0247)	(0.0094)	(0.0216)	(0.0148)	(0.0170)
LNURP	-0.6530*	0.4229*	-1.0027*	-0.6000*	-0.2770*
	(0.0485)	(0.0589)	(0.1174)	(0.0790)	(0.0925)
LNIND	2.3968*	-1.2358*	3.4185*	2.2418*	1.2979*
	(0.2546)	(0.2095)	(0.5354)	(0.3573)	(0.4222)
CONS	73.0442*	8.9767*			
	(1.4753)	(0.6091)			
Developing Countries					
EFP	-3.4342*	1.4695*	-4.5989*	-3.2350*	-2.1599
	(0.5925)	(0.5177)	(0.7738)	(1.1209)	(1.7140)
EFP^2	0.3097*	-0.1291**	0.4120*	0.2922**	0.1978
	(0.0729)	(0.0614)	(0.0923)	(0.1340)	(0.2051)
KOF	-0.6663*	-0.0667**	-0.6134*	-0.6753*	-0.7241*
	(0.0317)	(0.0256)	(0.0449)	(0.0651)	(0.0996)
LNURP	0.4975*	0.2885**	0.2689	0.5367	0.7477
	(0.1219)	(0.1102)	(0.2507)	(0.3640)	(0.5573)
LNIND	-3.4925*	-0.1417	-3.3802*	-3.5117*	-3.6153**
	(0.4750)	(0.2760)	(0.8150)	(1.1845)	(1.8149)
CONS	100.1367*	5.6217*			
	(2.2580)	(1.6025)			

Note: * $p<0.01$, ** $p<0.05$, *** $p<0.1$, () shows standard error

In addition to verifying the robustness of the main model, several control variables were also examined using the MM-QR approach. Among these, globalization, represented by the KOF Index, is found to significantly reduce the HVI across all quantiles in both models. This consistent negative relationship between globalization and HVI suggests that greater levels of globalization lead to improvements in health outcomes by mitigating vulnerability. These findings mirror the results obtained from the PQR approach, further confirming the robustness of the model. The alignment of these outcomes across different quantile estimation methods solidifies the conclusion that the influence of globalization on health vulnerability is both significant and consistent across various quantile groups, reinforcing the validity and reliability of the analysis.

Urbanization significantly shows a negative association with HVI in developed countries while a significantly positive association in developing countries. These results confirm that urbanization in developed countries uplifts health facilities by improving infrastructure and medical facilities. In developing countries, urbanization positively impacts the HVI. It shows that these countries have limited resources to invest in clean resources and health facilities that bring health problems and cause more deaths. These findings are also consistent with the findings of the PQR approach, which shows the robustness of the results.

Industrialization increases HVI in developed countries while declines in developing countries. These results show that most of the developed countries' industries rely on polluted energy resources, which adversely damage the health of the people. It spreads different diseases, which causes higher deaths. In contrast, developing countries have lower industries which emit lower emissions and benefits of the health sector. These results are consistent with the findings of the PQR approach.

Conclusions

This paper chapter discusses the empirical non-linear impact Environmental degradation with climate vulnerability. Environmental degradation is measured by using ecological footprint and climate vulnerability by health vulnerability. The study is model includes 97 developed and 62 developing countries, and a panel data was collected from 1990 to 2023. The bi-variate analysis between EFP and HVI shows non-linear trendlines in developed and developing countries. Before the estimation of the empirical results, different diagnostic tests are also conducted. The Pesran CD test shows the existence of cross-sectional dependency in the models. Furthermore, there also exists outliers and non-normality in the data, motivated using the PQR approach on three different quantiles at lower, middle, and higher quantile groups on 25%, 50%, and 75% quantiles. The empirical results were estimated by using the Panel Quantile Regression (PQR) approach, and the empirical results robustness was checked by using the Method of Movement Quantile Regression (MM-QR) approach.

The PQR approach shows a U-shaped relationship between ecological footprint and health vulnerability. The linearized marginal effects indicate that Luxembourg, Qatar, and the United Arab Emirates are located after the maturity of the U-shaped curve, while the remaining developed countries are located before the maturity side. Furthermore, the linearized marginal effect of developing countries shows that all developing countries are located before the maturity side. The study warns that if countries deplete natural resources at the same speed, they will push toward the right side of the U-shaped curve, which will cause more health vulnerability. This situation is dangerous because the developed countries have advanced health systems and resources, creating a false sense of security. Furthermore, this model also includes globalization, urbanization, and industrialization as the control variables. Globalization declines health vulnerability in all quantile groups. Industrialization displays mixed results; in developed countries, it increases health vulnerability, while in developing countries, it declines health vulnerability. Urbanization also shows mixed results; in developed countries, health vulnerability declines, while in developing countries, it increases health vulnerability. The robustness is checked using the MM-QR approach, which shows results similar to those of the PQR estimation.

Empirical findings suggest that the governments of all global countries should pay special attention to control the EFP, that may help to improve the climate sustainability and improves the health sector. Governments should enhance sustainable Economic Development, ultimately declining EFP and HVI. This research work may be further extended for future research to analyze the moderating role of institution quality on the relationship between environmental degradation and climate vulnerability in both developed and developing countries.

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