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Measuring the asymmetric effect of corruption on environmental degradation in Pakistan: role of human capital

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Abstract
The paper investigates the effect of corruption and human capital on environmental degradation, measured by CO_2 and SO_2 emissions, in Pakistan from 1980 to 2020. The indirect (moderating) effect of human capital on environmental degradation is also examined via the interactive term of corruption and human capital. The Bound-testing approach to Autoregressive Distributed Lag Model and Non-Liner ARDL are employed for measuring linear and asymmetric effect of corruption on environmental degradation, respectively. The findings suggest that corruption tends to increase environmental degradation while the effect tends to decline with growing human capital. The study also verifies the existence of Environment Kuznets Curve hypothesis for Pakistan. Additionally, the marginal effect of corruption on carbon emissions shows a tendency to decline significantly, at successively higher percentiles of human capital and offers a mitigation of about 6 to 13%. Furthermore, the study provides an asymmetric effect of corruption on CO_2 emission, via positive and negative shocks, both in the short and long run. The findings call in question the corruption dynamics of environmental degradation and urges to control the corruption with stern accountability of the committers to avoid further depletion of environment. The study suggests enhancing the role of human capital to deal with both menace effectively.

Keywords Corruption · Environmental Degradation · Human Capital · Pakistan

1 Introduction

Climate change has become the world's most complex governance challenge and has been widely debated in literature. With the rising emissions of greenhouse gases (GHGs) and consequential environmental degradation, it has become a perilous non-traditional security threat (Nordas & Gleditsch, 2009).[1] Although climatic variations emerged long time ago, gradual anthropogenic climate changes have intensified the concerns manifold. It adversely affects basic needs of life including water, air, food, and human habitat which upheavals

[1] The sulfur dioxide (SO_2), nitrogen oxide (NO_X) and water pollution are other gases responsible for the climate change leading to environmental degradation.

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malnourishment, morbidity, mortality, and economic insecurity (Otto et al., 2017). Moreover, GHGs emissions create negative externalities for developing countries if adaptive measures have not been taken (Zhang et al., 2018).

According to Global Climate Risk Index (2021) by Germanwatch, developing countries are the most affected regions by climate change due to high vulnerability and low adaptation. Pakistan's position in Global Climate Risk Index is reported as 8th most vulnerable country to the climate change and the country has remained among the top ten most affected countries by climate change.[2] Pakistan has lost numerous lives and incurred economic damage worth US$ 3.8 billion from 2000 to 2019. Moreover, the economic loss attached to climate risk-related vulnerability shows a loss of 0.52 percent of Gross Domestic Product (GDP) over last two decades.[3] According to National Electric Power Regulatory Authority's (2021), 63 percent of energy in Pakistan is based on fossil fuels and about 40 percent of primary energy supply of the country is being imported. The country's total emissions are 2.4 tonnes of CO_2 equivalent per capita and its annual share in global CO_2 emission was about 0.60 percent in 2019 as compared to 0.46 percent in 2010, an increase of almost 30 percent over the 10 years' time period. The energy and agriculture sector of the country contributes 87 percent of the national GHG emissions. Specifically, energy sector contributes 46 percent while agriculture sector accounts for 41 percent to the total GHGs emissions, according to World Resources Institute's Climate Analysis Indicator Tool.[4]

Besides, emissions from transport sector have increased tenfold as a result of massive infrastructure projects under China-Pakistan Economic Corridor (CPEC). Furthermore, the agglomeration of industries in the form of industrial hubs and cities also adds to industrial pollution. According to Global Carbon Project (2022), consumption-based CO_2 emission was 246.01 million tons and production-based emission was 234.29 million tons in 2018. Similarly, level of SO_2 emissions was highest during 1990 s as the major source of fuel was diesel for transport.[5] Overall, Pakistan ranked 176 out of 180 countries on environmental performance index implying poor environmental quality.[6]

Pakistan has taken various measures to introduce legislation for environmental protection since 1977. The environmental consideration was given due weightage in national planning in 1990 s and a number of environmental regulations and protection laws have been laid down. A major milestone was the adoption of National Conservation Strategy (NCS) in 1992, focusing mainly on conservation which proved crucial in transforming public attitudes and modifying consumption patterns. Similarly, environment protection agencies remained the hallmark of sustainability during late 80 s and early 90 s, both at the federal and provincial level.[7] Subsequently, Environmental Protection Act (1997) and National Conservation Policy (2005) surfaced with a focus on protection, conservation, rehabilitation and the restoration of efforts to meet sustainable development goals (Nadeem et al.,

[2] The index is based on the analysis of climatic risk extent data in the form of storms, floods and heatwaves and is conducted for last 20 years.

Retrieved from https://reliefweb.int/report/world/global-climate-risk-index-2021.

[3] Retrieved from Pakistan CO_2: Country Profile, Our World in Data.

[4] Retrieved from Calculations using data from World Resources Institute Climate Analysis Indicators Tool (WRI CAIT) 2.0, 2015.

[5] Retrieved from https://www.globalcarbonproject.org/.

[6] Retrieved from https://epi.yale.edu/epi-results/2022/component/epi.

[7] Accessed from https://www.commissiemer.nl/docs/os/sea/casestudies/16_pakistan_national_conservation_strategy.pdf.

2022). A newly unveiled National Adaptation Plan (NAP) spanning the years 2023–2030 also holds the promise of yielding impactful outcomes in the years to come.

Despite many measures taken by the country to combat environmental degradation, efforts remain partially effective due to a deregulated nature of industries in the country. Industrial activities responsible for polluting air and water remain widely unchecked. The extended car financing and limited investment in public transport have added the transport load on roads. These factors are responsible for heavily polluting the environment, especially in the absence of standardized inspection in place. Despite establishing several ministries, departments, and action groups to address the issue, situation has not been improved for Pakistan. The responsible institutions are highly vulnerable to the risk of corruption due to undue influence on the implementation of regulations, misallocation of funds, and concealment of facts and figures with misreporting and exploitation of verification mechanism.[8] The nationalization policy of 1970 gave birth to a new form of corruption in Pakistan. During 1990s, two major political parties remained in power but both governments were overturned due to corruption charges. National Accountability Bureau (NAB) was established to investigate corruption cases in 1999 but the lack of political will along with weak institutional setup obstructed the way towards fight against corruption. National anti-corruption strategy was also formulated in early 2000s however, not a promising scenario has emerged in controlling corruption so far.

Both menaces discussed above, corruption and environmental degradation, share certain features, as the most vulnerable countries to climate change are almost the same which are low performers at the Control of Corruption Perception Index (CPI).[9] Pakistan ranked 140th out of 180 countries at the CPI, indicating a poor control of corruption and rank 8th at climate change risk index indicating high vulnerability. Hence, the corruption dimension of climate change is worth investigating.

An important factor that can play effective role in limiting environmental degradation is human capital that can not only impart direct positive impact on environmental quality but can also offset the adverse effects of corruption on environment. The traditional human capital theories, termed as the first generation of human capital theories, pioneered by Schultz (1961), Mincer (1958) and Becker (1964), emphasizes on the productivity aspect of human capital. The theory indicates that higher productivity pays off in the form of high rate of return and the productive capacity of individuals tends to increase due to high rate of return, alternatively. Today, human capital is a well-known concept and is being recognized as the most critical factor in knowledge economy and the welfare (Hartog and Brink, 2007).

However, there are also some other positive externalities associated with qualified human capital, leading to spillover effects. According to Goetz et al. (1998), education, skills, and awareness embodied in human capital leads to better perception of environmental quality. The quality human capital possess skills to innovate production and consumption practices in reducing carbon emission. They can raise environmental awareness at the household, community and national level, promoting such practices that tend to decrease in environmental degradation. The traditional role of human capital in economic growth and its consequent spillovers to improve the quality of life and welfare is albeit pertinent. However, for sustainable economic growth human capital

8 Such practices are embedded in corruption defined as "the abuse of entrusted power for private gain" by Transparency International and is quite evident from the transaction in public and private spheres.

9 See 'CGR Climate Change: The User Guide' for details.

can play a profound role, where the connection between human capital and environment becomes inevitable.

On the other hand, educated and qualified individuals are also expected to be more sensitive to corrupt practices related to climate change actions. They can become potential contributors to corruption-free practices, resulting in less polluted production and consumption practices. Human capital, representing the collective knowledge, skills, and integrity of a population, is a key determinant in curtailing corruption, in this regard. The corrupt practices often divert resources away from productive to unproductive use, leading to rent-seeking behavior that accentuates environmental degradation. In contrast, well-educated and ethically sound human capital can serve as a potent force against corruption by fostering a culture of accountability, transparency, and good governance.

From that context, this study is an attempt to measure linear and asymmetric effect of corruption on environmental degradation, by employing Autoregressive Distributed Lags (AEDL) and Non-Linear ARDL (NARDL) techniques for Pakistan for 1980 to 2020. The study also investigates the direct and moderating role of human capital in environmental degradation. Other control variables are GDP per capita and its square, Foreign Direct Investment (FDI), trade openness, population density, institutional quality, government expenditures on education, and energy consumption.

The study verifies the existence of Environment Kuznets Curve (EKC), an inverted U-shape relationship between economic development and environmental degradation, for Pakistan and shows that faster economic growth is necessary for turning EKC. Moreover, the findings of the study also show that corruption has an asymmetric effect on environmental degradation-positive shocks in corruption worsen the environmental conditions, while negative shocks, indicating better control of corruption, tend to decline environmental degradation. Moreover, human capital plays the moderating role in the long-term relationship between corruption and environmental degradation. The study also highlights the negative and significant impact of FDI and population density per area on environment, while institutional quality and government expenditures on education play positive role in mitigating environmental degradation.

The rest of the study is organized as follows. Section 2 provides review of literature. Section 3 provides methodology and Sect. 4 reports and discusses empirical findings. Section 5 concludes the study with some policy implications and the last section provides limitations of the study.

2 Literature review

2.1 Theoretical underpinning

The theoretical foundation for understanding the interconnected dynamics of corruption, environmental degradation, and human capital stems from Environmental Kuznets Curve (EKC) hypothesis proposed by Grossman and Krueger (1991). The EKC illustrates an inverted U-shape relationship between per capita income and pollution concentration. According to this hypothesis, environmental quality tends to deteriorate in the initial stages of economic development, corresponding to lower levels of per capita income, reaches a peak, and subsequently improves as per capita income continues to rise. Apart from per capita income, a conventional determinant of environmental quality, some other factors are also investigated in literature which offer diverse impact on environmental quality. These factors include trade liberalization, energy consumption, population, institutional quality, and governance, among others (Le & Ozturk, 2020).

From that context, corruption may be another factor responsible for impairing environmental quality through various channels. Firstly, corruption give birth to malpractices in resource extraction, management, permitting system, and inspection that get translated into degrading environment (Lisciandra & Migliardo, 2017). The corrupt practices contribute to the formulation of such policies that might not be environment friendly and generally invite to divert the resources to environment unfriendly practices. This also cause delays in the implementation of environmental laws and regulations (Wu et al., 2020). Furthermore, industrialists involved in pollutant production practices offer bribes to bureaucrats to avoid penalties which also affect environment adversely (Varvarigos, 2023). Secondly, personnel involved in corruption use environment-unfriendly technologies and misreport their actions which enables them to receive undue subsidies. This creates more externalities and adds on in polluting the environment (Acemoglu & Verdier, 2000).

On the other hand, human capital (in the form of better education and awareness) leads others in perceiving potential benefits of quality environment. As argued by Goetz et al. (1998), as the educated individuals are more likely to realize the harmful effects of environmental degradation and are able to perceive greater utility attached to future environmental pay-offs, they are more inclined to promote environment-friendly practices. Moreover, high-quality human capital can introduce fresh ideas and are capable of adopting new technologies, thus promoting innovations aimed at reducing carbon emissions. A growing body of literature underscores the pivotal role of human activities are critical factors in environment degradation. According to the US National Climate Assessment (2018), human are the primary source of pollution, emitting greenhouse gases through the combustion of fossil fuels, which stands as the predominant cause of environmental degradation. Conversely, it holds also true that environmental degradation can be mitigated through the positive contributions of human capital. According to Zhang et al. (2021), human capital and environment awareness are significant contributors in environmental protection in the course of economic growth. Developed countries have experienced exponential growth by expanding scientific and technical knowledge embodied in human capital and enhancing the productivity of factor inputs in the production process.

In the context of corruption, a well-educated person may contribute to maintenance and development of such institutions that effectively prevent corruption. According to institutional theory, role of an institution is crucial in shaping economic behavior. Luo (2005) while giving an organizational perspective of corruption, utilizes the institutional theory to provide insights into why corruption get settled in the roots despite the introduction of anti-corruption laws and regulation. Particularly, informal institutions that include culture, customs and norms, while formal institutions, including law and regulation, develop structure of economic interaction of individuals with society. Human capital, in the form of education, can develop norms, values and culture that discourage corruption. In societies with historically low trust in public institution, there may be higher inclination towards corruption, navigating an untrustworthy system. A culture that exhibits a high level of tolerance for bribery is more likely for individuals to engage in corruption. Formal education generates a sense of civic responsibility, raising awareness of the importance of integrity (Pillay & Dorasamy, 2010). Hence, qualified human capital display ethical norms and values, not only in better understanding of the negative consequences of corruption but also in proving themselves pivotal in suppressing corruption, thereby preventing environmental degradation. This debate also sets the stage for understanding the role of institutional quality in the interconnection between corruption and environmental degradation.

2.2 Empirical review

The empirical literature on corruption and environmental quality provides compelling evidence of the adverse impact of corruption on environment. It delves into how bureaucratic and lobbying groups exploit the implementation of environmental policies and regulations. For instance, Lopez and Mitra (2000) investigate the relationship between pollution and economic growth with the intervening role of corruption and rent-seeking behavior of the government. According to the study, regardless of the type of cooperation between the firm and public authority, pollution levels generally remain higher than the socially ideal level.

Apart from the directly adverse effect of corruption, it becomes also evident that various policies do not operate effectively in the presence of corruption. Damania et al. (2003), for instance, demonstrate that corruption amplifies the negative impact of trade liberalization on environment. Fredriksson and Svensson (2003) illustrate that political instability jeopardizes the implementation of environmental rules and regulations in the presence of a high level of corruption. Cole (2007) concludes that corruption has a direct positive impact on GHGs emissions for a panel of 94 countries from 1987 to 2000, while indicating an indirect negative effect on GHGs emissions through the channel of per capita income. The study emphasizes that reducing corrupt practices, coupled with better environmental legislation, is essential to improve environmental quality.

Rehman et al. (2012) investigate the role of corruption in affecting the socially optimal level of GDP for environmental degradation and conclude that corruption delays the turning point of EKC. Similarly, Zafar et al. (2013) investigates the impact of trade liberalization and corruption on environmental degradation in Pakistan for 1980–2011, using CO_2, SO_2 and water pollution as environmental indicators. The study proves the existence of short and long-run EKC in Pakistan. Moreover, trade openness is found to have a favorable impact on environment. Ertugrul et al. (2016) show a significant relationship among CO_2 emissions, economic growth, trade openness, and energy use in the EKC framework, for a panel of ten developing countries during 1971–2011. Chen et al. (2018) investigate the role of shadow economy and corruption on environment in China during 1998–2012. The results determine that loose environmental regulations and shadow economy lead to an increase in environmental pollution. Sinha et al. (2019) analyze how corruption affects carbon emissions in the presence of segregation in energy use. The study found N-shape EKC in BRICS (Brazil, Russia, India, China, South Africa) and the Next 11 countries. The results found that corruption reduces the positive effect of renewable energy consumption on environmental quality and increases the negative impact of fossil fuel consumption. Habib et al. (2020) also investigate the direct and indirect effect of corruption on environmental degradation for eighteen African countries from 1992 to 2013. The study figures out negative impact of corruption on CO_2 emissions in lower-emission countries, whereas in higher-emission countries the effect becomes insignificant. Similarly, a study by Sekrafi and Sghaier (2018) conducted for 13 countries in the Middle East and North African region for 1984–2012, examine the relationship among corruption, environmental quality, energy consumption, political instability, and economic growth. The results show that corruption has directly significant impact on economic growth, environment and energy consumption, while it has an indirect effect on economic growth through energy consumption and environmental quality. In a study for Pakistan, Idrees et al. (2023) assert that corrupt practices reduce economic growth due to individuals' rent-seeking behavior and their preference over the socially productive activities. Using data from 1984 to 2014, cointegration test results show that despite institutional growth, environmental degradation keeps on rising due to lack of policy and weak implementations. Arif et al., (2022a, 2022b) examines the relationship between CO_2 emissions, energy consumption, financial development, governance index, and economic growth for the quarterly data from 196 to 2018. The study show that financial development and energy consumption increases environment pollution while governance tends to reduce it. The study supports the existence of EKC for Pakistan.

The literature on human capital and its impact on environmental degradation presents mixed evidence. One prominent empirical work, conducted by Goetz et al. (1998) for state-level data, concludes that states with larger share of young population with more completed years of schooling are more environmentally conscious. From the same context, Saleem and Shujah-ur-Rahman (2019) carry out a study to investigate how human capital and bio-capacity affect the environment in BRICS countries during 1991–2014 and Chinese provinces from 1996 to 2008. The study confirms the existence of long-run cointegrating relationship among selected variables and presence of inverted U shape EKC for environment degradation and per capita income, with a positive contribution of human capital. In another study by Zhang et al. (2021), impact of human capital, natural resources and economic growth on environmental quality is investigated for Pakistan from 1985 to 2018. The study supports EKC hypothesis, employing a dynamic autoregressive distributive lag model. Moreover, the long-run estimates show that human capital and natural resources have negative association with CO_2 emission while positive with ecological footprint. While exploring the nexus between human capital and environmental degradation for the countries of European Union at different financial level, Çakar et al., (2021) provided moderating effect of human capital on carbon emissions and suggested that with improving human capital there would be more innovations to protect the environment and lower environmental degradation. For a panel of OECD countries in a recent study by Hondroyiannis et al. (2022), new insights are offered on the role of human capital in environmental degradation for the time period 1980–2019. The study used indirect measure for human capital i.e. government expenditures on education and suggested that human capital tends to reduce energy consumption and carbon emissions. In the same vein, the case study of Turkey conducted by Çamkaya et al. (2022) established long-run effect of human capital in improving environmental quality for time period 1980–2018. Similarly, another case study of Sri Lanka conducted by (Adikari et al., 2023) for the time period 1978–2019 employed Autoregressive distributed lag model (ARDL) and confirmed long-run association between the human capital and environmental degradation.

The literature enables us to establish that corruption has negative while human capital has positive effect on environment quality distinctly but the question remains: whether human capital plays a mitigating role in the nexus of corruption and environment quality. The present study contributes to the existing literature by examining said relationship empirically for Pakistan for an extended time period (1980–2020), not covered by earlier studies. Keeping in view the possible non-linearity of the relationship, the study also examines asymmetric effect of corruption on environmental degradation by employing non-linear ARDL, providing both short and long-run estimates. Other relevant variables are also controlled in the model for the robustness of empirical findings.

3 Methodology

3.1 Theoretical framework

One of the most popular tools to understand the relationship between economic development and environment is Environmental Kuznets Curve (EKC), named after Kuznets (1955). The concept of EKC hypothesis was first introduced by Grossman and Krueger (1991) and popularized by the World Bank Report (1992) on 'Development and the Environment.' The hypothesis states that environmental degradation first rise and then fall with the increase in GDP per capita and yields an inverted U-shape curve. The said relationship is based on three countervailing effects namely first, the scale effects that explains pollution tends to increase with the increasing scale of growth if technology and structure of economy remain unchanged. The traditional view about economic development and environmental quality, for being conflicting goals, reflects the scale effect. Second, the composition effect which shows that environmental degradation may either increase or decrease with an increase in output as certain sectors of the economy grow relatively more as compared to others. Third, the technique effect shows that pollution is likely to decrease with economic output as technology makes production less pollution-intensive and/or citizens demand a cleaner environment. Overall, EKC postulates that scale effect dictates at the initial stages of development while at the later stages, composition and technique effects dominates (Dinda, 2004).

The role of human capital in EKC debate can enter both directly and indirectly. The standard approach considers human capital as a set of skills and characteristics that enhances labor's productivity. The pioneers in Human Capital Theory (e.g., Becker, 1964; Mincer, 1958; Schultz, 1961) presents human capital as investment decisions of both public and private entities. Human capital, as a critical input in production function, has been considered an engine of growth in literature. In the exogenous growth theory, Solow (1956) introduced residual term in the growth accounting framework in 1950 s and viewed it as knowledge creation and the augmented labor input through education and training, referred as effective human capital. Human capital theory informs that educated population is more productive and formal education is the investment which is equally or even more worthwhile than physical capital (Psacharopoulos & Woodhall, 1997). The theory relates to the knowledge economy because it asserts that more educated person becomes more productive and a positive contributor to the society. Intrinsically educated and well-informed human capital tends to improve total productivity, reduces the criminal activities and promote innovations (Goldin, 2016).

Far along the treatment of human capital as an endogenous factor, introduced in endogenous growth theory (Romer, 1986 and Lucas, 1988), embodies scientific knowledge and skills that entails endogenously determined economic growth. Human capital poses positive externality that restrains diminishing returns to scale due to its spillover effects. It is argued that physical capital cannot efficiently transmit from the developed countries to the developing countries due to weak endowments of complementary human capital. And in that case, the adoption of environment friendly technologies in the developing countries like Pakistan signifies the role of human capital, furthermore. The literature on human capital postulates distinct effects on the quality of environment in this regard (Yao et al., 2020; Grossman & Krueger, 1995; Cango and Trianni 2013; Li & Ullah, 2022). This provides us the background for linking human capital with reducing environmental degradation.

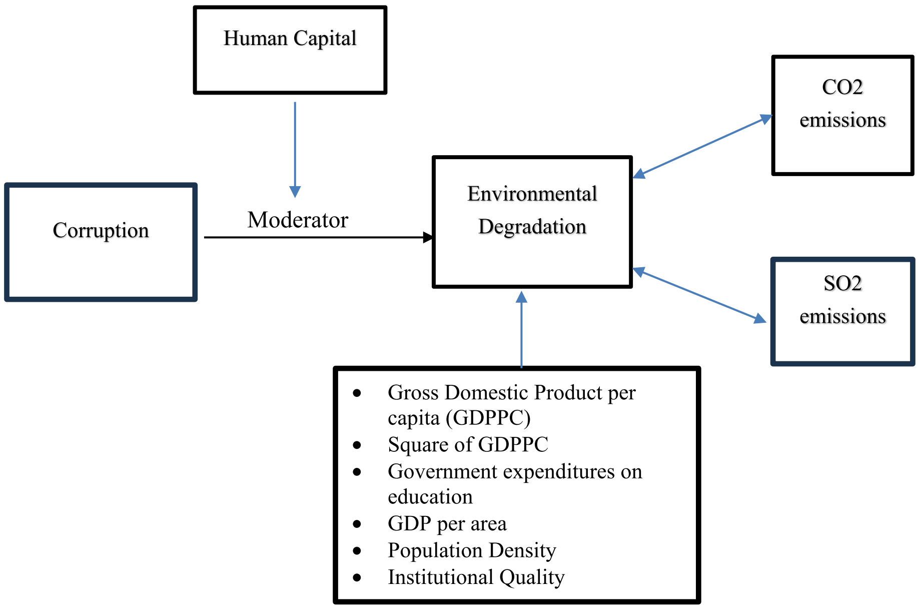

Fig. 1 Conceptual framework of asymmetric effect of corruption and human capital on environmental degradation *Source*: Author's computations

Turning to the debate on corruption and its connection with environmental degradation, corruption in natural resources has been the main cause of environmental degradation. Tax avoidance and rent-seeking behavior of polluters evade regulations being imposed on toxic effluents and other waste materials of industrial products, specifically. Corruption can also influence the environment in informal sectors including brick mining, transportation, leather tanning, and other inefficient production processes at small scale. Moreover, the weakness of regulatory control in the informal sector also accentuates environmental degradation (Biswas et al., 2012). The asymmetric effect of corruption is investigated with the expectations that a negative shock in corruption has statistically significantly different effect on environmental degradation and can offer insight into appropriate policy measures to be taken for handling the menace of environmental degradation effectively. The magnitude of parameters support us in gauging that which shock (positive or negative) is paramount for the environment. Moreover, the long and short-run effects of corruption change also varies from both context. Hence, following Shin et al. (2014) approach, we have decomposed focused variable (corruption) into positive and negative shocks and the NARDL approach is used as most appropriate estimation technique to effectively deal the problem of endogeneity which is most likely in the case of our variable selection and model specification. The application of both ARDL and NARDL also shows robustness of the empirical findings.

The theoretical framework is expressed in one picture in Fig. 1.

3.2 Empirical model

The empirical model is adapted from Grossman and Krueger (1991, 1995) by adding variables of interest i.e., corruption, human capital, and their interaction term along with other control variables. The baseline equation is specified as below:

$$LnED_t = \beta_0 + \beta_1 Corr_t + \beta_2 lnHKI_t + \beta_3 \ln\left(Corr_t * HKI_t\right) + \beta_4 lnGDP_t + \beta_5 lnGDP_t^2 + \sum_{i=6}^{k} \beta_i X_{it} + \mu_i \tag{1}$$

where *ED* refers to Environmental Degradation which is measured by Carbon Emission, CO_2, and Sulphur Emission, SO_2, as the function of corruption, *Corr,* stock of human capital, *HKI,* an interaction term of corruption and human capital, *Corr*HKI,* to observe the moderating role of human capital in corruption-environmental degradation relationship, *GDP and GDP square* to verify the EKC and X_t stands for other control variables; population density, government expenditures on education, foreign direct investment, GDP per area and institutional quality.

3.3 Estimation technique

The model is estimated by applying Autoregressive Distributed Lag Model (ARDL) of Pesaran and Shin (1999, 2001) that is based on Bound-testing approach to Cointegration and is appropriate technique in the presence of a set of variables possessing combination of integration of order zero, I (0) and one, I (1), as is the case here. Moreover, the technique is more suitable for cointegrating relationship among the variables for small samples (Haug, 2002). The approach accommodates appropriate modification of the lag order of variables which simultaneously corrects the residual serial correlation and possible endogeneity in the model as well (Pesaran & Shin, 1999). Moreover, as the approach does not demand symmetry in the lag length of variables it makes the model more dynamic and comfortable in providing long-run responses along with short-run adjustments.

3.3.1 Autoregressive distributed lag model (ARDL) specification

The Autoregressive Distributed Lag Model (ARDL) specification of Eq. (1) is given as below:

$$\Delta LnED_t = \alpha + \sum_{i=1}^{p} \beta_i \Delta LnED_{t-i} + \sum_{i=0}^{q} \gamma_i \Delta Corr_{t-i} + \sum_{i=0}^{q} \xi_i \Delta HKI_{t-i} + \sum_{i=0}^{q} \phi_i \Delta ln(Corr * HKI)_{t-i} + \sum_{i=0\,i}^{q} \Gamma_i \Delta LnGDP_{t-i} + \sum_{i=0\,i}^{q} \varsigma_i \Delta LnGDP^2_{t-i} + \sum_{i=0}^{q} \psi \Delta X_{t-i} + \delta_1 LnED_{t-1} + \delta_2 Corr_{t-1} + \delta_3 HKI_{t-1} + \delta_4 ln(Corr * HKI)_{t-1} + \delta_5 LnGDP_{t-1} + \delta_6 LnGDP^2_{t-1} + \delta_7 X_{t-1} + e_t \quad (2)$$

The error correction model of ARDL is specified as:

$$\Delta LnED_t = \alpha + \sum_{i=1}^{p} \beta_i \Delta LnED_{t-i} + \sum_{i=0}^{q} \gamma_i \Delta Corr_{t-i} + \sum_{i=0}^{q} \xi_i \Delta HKI_{t-i} + \sum_{i=0}^{q} \phi_i \Delta ln(Corr * HKI)_{t-i} + \sum_{i=0\,i}^{q} \Gamma_i \Delta LnGDP_{t-i} + \sum_{i=0\,i}^{q} \varsigma_i \Delta LnGDP^2_{t-i} + \sum_{i=0}^{q} \psi \Delta X_{t-i} + \lambda EC_{t-1} + u_t \quad (3)$$

where λ refers to the speed of adjustment of residual and *EC* stands for error correction. The two imperative conditions of serially uncorrelated error terms and stability of the model are tested by Breusch-Godfrey Correlation LM test and negatively significant error correction term, respectively. Moreover, the long-run relationship among the variables is verified by the Bound testing approach to cointegration.[10]

3.3.2 Nonlinear autoregressive distributed lag model (NARDL) specification

Additionally, Nonlinear ARDL (NARDL) model introduced by Shin et al. (2014) suggested a cointegrating nonlinear model which decomposes the explanatory variables by taking partial sum of positive and negative changes and offers asymmetric cointegrating relationship, with a dynamically flexible ARDL model. The method has certain advantages like it improves the performance of model in small samples, particularly in term of power of the cointegration test. This approach is more flexible as this estimates long- and short-run asymmetries simultaneously and provides the test for long- and short-run symmetry restrictions.

The NARDL specification of Eq. (1) is given as below:

$$LnED_t = \beta_0 + \beta_1 Corr\_POS_t + \beta_2 Corr\_NEG_t + \beta_3\, lnGDP_t + \beta_4 lnGDP^2_t + \beta_5\, lnHK_t + \sum_{i=6}^{k} \beta_i X_{it} + \mu_t \quad (4)$$

where $Corr\_POS_{t,}$ and $Corr\_NEG_t$ refers to the partial sum of higher than-average and lower- than-average corruption, respectively. The NARDL specification of model (4) is given as below:

[10] As the critical values of Pesaran et al (2001) are recommended for large sample, Narayan (2005) suggested the critical values for a sample between 30 to 80 observations as 2.496-3.346, 2.962-3.910 and 4.068-5.250 at 10%, 5% and 1% level of significance, respectively.

Table 1 Description of variables

Variables	Measurement	Data source	Mean
ED	Environmental degradation measured by Carbon dioxide emission, CO_2 in metric tons per capita and Sulfur dioxide emission, SO_2 measured in kilo tons	World Development Indicator and Regional Emission Inventory in Asia (REAS)	0.736 & 17.19
Corr	Corruption perception index ranges from 0–6 where 0 indicates highest corruption and 6 indicates lowest corruption. The variable is rescaled following Benfratello et al., (2018) and Cooray, et al., (2016) and hence, the minimum value indicates least corruption while maximum value shows high corruption	International Country Risk Guide (ICRG) by Political Risk Service (PRS) group	1.97
HKI_t	Human capital index based on average years of schooling (Barro & Lee, 2013) and an assumed rate of return to education, based on Mincer's (Psacharopoulos, 1994)	Penn World Table 9.0	1.55
GDP	Log of Gross Domestic Product per capita (Constant local currency unit)	World Development Indicator	10.68
GDP^2	Square of log Gross Domestic Product per capita	World Development Indicator	40.05
FDI_t	Foreign Direct Investment net inflows (as % of GDP)	World Development Indicator	1.41
GEE	Government expenditures on education as percentage of GDP	World Development Indicator	2.42
GDPPA	GDP per area (log)	World Development Indicator	15.83
PD	Population Density measured as people per sq. km of land area	World Development Indicator	5.16
IQ	Institutional quality measured by polity index ranges from − 10 (full autocracy) to + 10 (pure democracy)	Polity-IV published by the Center for Systematic Peace (CSP)	1.74

$$\Delta LnED_t = \alpha + \sum_{i=1}^{p} \beta_i \Delta LnED_{t-i} + \sum_{i=0}^{q} \gamma_{i1} \Delta Corr\_POS_{t-i} + \sum_{i=0}^{q} \gamma_{i2} \Delta Corr\_NEG_{t-i} + \sum_{i=0}^{q} \xi_i \Delta HKI_{t-i} + \sum_{i=0\,i}^{q} \Gamma_i \Delta LnGDP_{t-i} + \sum_{i=0\,i}^{q} \varsigma_i \Delta LnGDP^2_{t-i} + \sum_{i=0}^{q} \psi \Delta X_{t-i} + \delta_1 LnED_{t-1} + \delta_2 Corr\_POS_{t-1} + \delta_3 Corr\_NEG_{t-1} + \delta_4 HKI_{t-1} + \delta_5 LnGDP_{t-1} + \delta_6 LnGDP^2_{t-1} + \delta_7 X_{t-1} + e_t \quad (5)$$

This follows the error correction model for NARDL as below:

$$\Delta LnED_t = \alpha + \sum_{i=1}^{p} \beta_i \Delta LnED_{t-i} + \sum_{i=0}^{q} \gamma_{i1} \Delta Corr\_POS_{t-i} + \sum_{i=0}^{q} \gamma_{i2} \Delta Corr\_NEG_{t-i} + \sum_{i=0}^{q} \xi_i \Delta HKI_{t-i} + \sum_{i=0\,i}^{q} \Gamma_i \Delta LnGDP_{t-i} + \sum_{i=0\,i}^{q} \varsigma_i \Delta LnGDP^2_{t-i} + \sum_{i=0}^{q} \psi \Delta X_{t-i} + \lambda EC_{t-1} + u_t \quad (6)$$

Wald-coefficient test is applied to test the equality (inequality thereof) of the two directions of corruption change $\left[\beta_1 = \beta_2\right]$ while the joint significance of parameters is determined by equating $[\beta_1 = \beta_2 = 0]$.

3.4 Variable construction and data description

Table 1 provides the data description in detail.

GDP and its square are expected to provide non-linear inverted U-shape relationship with GHGs emissions, confirming EKC for Pakistan, as is supported by earlier case studies (Rehman et al., 2012; Shahbaz et al., 2012). We can also compute the optimal tipping point from the estimated equations. Corruption is expected to increase environmental degradation by delaying the formulation and implementation of environmental protection policies, due to corrupt officials accepting bribes to conceal the emission of hazardous gases and avoiding penalties (Cole, 2007; Rehman et al., 2007; Welsch, 2004). The study further investigates whether human capital plays moderating role in environment degradation-corruption nexus. Human capital is expected to reduce GHGs emissions. A recent study by Kim and Sun (2020) investigates the said relationship at country level and identifies human capital as a contributing factor in improving environment performance index for a sample of countries (excluding Pakistan). Although the role of HK is not novel in literature, incorporating it in the environmental degradation and corruption relationship can offer interesting insights. The expected impact of human capital in corruption and environmental degradation nexus is moderating. With the educational attainments, qualified human capital tend to adapt green technology. This also creates awareness about the urgency of environment preservation and the potential risk of corruption involved in production practices which can lead to increasing environmental degradation in future. A number of indicators have been used to measure human capital inclusive of School Enrolments Rates, literacy rate, average years of schooling and human capital index (Feenstra et. al., 2015) that comprised of average years of schooling suggested by Barro and lee (2013) and returns to education provided by Pscaropoulous (1994). We have used human capital index that is based on average years of schooling (Barro & Lee, 2013) and an assumed rate of return to education, based on Mincer's (Psacharopoulos, 1994), to capture human capital more comprehensively.

Table 2 Unit root test results

Variables	Level	1st Diff.	Decision
LnCO2 per capita	−1.84 (0.6635)	−8.99* (0.000)	I(1)
LnGDP	−2.43 (0.3576)	−3.61* (0.043)	I(1)
LnGDPSq	−3.73* (0.0337)	–	I(0)
LnCorr	−2.85 (0.1903)	−8.03* (0.000)	I(1)
LnHki	−4.887* (0.046)	–	I(0)
LnFDI	−2.07 (0.5446)	−5.42* (0.0004)	I(1)
LnEC	−0.580 (0.9737)	−5.40* (0.0006)	I(1)
LnTrade	−2.737 (0.2282)	−7.18* (0.0000)	I(1)
LnPD	−5.729* (0.000)	–	I(0)
Pol2	−1.765 (0.702)	−5.613* (0.000)	I(1)
LnGDPpa	−3.650 (0.040)	−3.727* (0.0328)	I(1)
GEE	−1.854 (0.658)	−4.789* (0.002)	I(1)

The critical values are −4.227, −3.537 & −3.200 at 1%, 5%, and 10% level of significance, respectively

* indicates significance at first difference

FDI is expected to yield positive sign if it promotes the use of green technology. Technology-driven capital can reduce energy intensity and supports the environment by adopting renewable energy sources (Li & Ullah, 2022). However, if the country has been treated as pollution heaven by the foreign investors, due to lack of environmental regulations, the impact of FDI might be negative both in the short and the long-run (Arif et. al., 2022; Asghari, 2013; Golub et al., 2011). Government expenditures on education can provide a cross check of the impact of human capital on environmental degradation, following Hondroyiannis et al. (2022) approach and is expected to decrease environmental degradation. Population density is expected to deteriorate environment quality due to rising population pressure per square area km, competition for the available resources and high carbon footprints. On the other hand, institutional quality is expected to have negative effect on environment degradation.

4 Empirical results and discussion

The empirical findings based on ARDL and NARDL estimation are reported in Table 3. The stationarity properties of the variables are first checked through Augmented Dickey-Fuller (ADF) test, reported in Table 2. The results provide a combination of order of integration at level and first difference of selected variables and provide the justification for applying ARDL approach to Cointegration.

The results of ARDL & NARDL are reported for CO_2 and SO_2, with and without controlling institutional quality in Table 3, reported as Eqs. (1–4), respectively. Overall, results provide consistent set of estimates in eight specifications of the model which is an indication of robustness of results. The diagnostic test results show the goodness of fit of the empirical models. For instance, Wald test verifies statistically significant asymmetries in the impact of corruption on environmental degradation and signifies the diverse impact of positive and negative shocks of corruption on environmental degradation, captured through NARDL technique. The result of bound test shows the F-statistic values greater than upper

Table 3 Long run and short run estimates of ARDL & NARDL

Variables	Ln CO_2 per capita				Ln $S0_2$ per capita			
Specifications	ARDL		NARDL		ARDL		NARDL	
	With IQ	Without IQ	With IQ	Without IQ	With IQ	Without IQ	With IQ	Without IQ
Long run estimates								
LLnGDP	1.984* (0.666)	2.091* (0.549)	0.714** (0.368)	0.865** (0.331)	2.105* (0.609)	0.854 (0.802)	1.488* (0.416)	1.598** (0.698)
LLnGDPSQ	−0.996* (0.332)	−1.049* (0.274)	−0.360** (0.184)	−0.432** (0.167)	−1.045* (0.337)	−0.431 (0.402)	−0.735* (0.212)	−0.797** (0.353)
Corruption	0.138*** (0.077)	0.143* (0.046)	–	–	0.566*** (0.297)	0.403*** (0.218)	–	–
Corr_PS	–	–	0.044 (0.035)	0.051*** (0.027)	–	–	−0.022 (0.054)	−0.056 (0.064)
Corr_NEG	–	–	−0.033*** (0.020)	−0.044*** (0.023)	–	–	0.119 (0.087)	0.047 (0.049)
Human Capital	−0.654*** (0.342)	−0.329*** (0.187)	−0.708* (0.275)	−1.102*** (0.611)	−3.071* (0.665)	−2.658* (0.522)	−4.424* (1.244)	−3.717* (0.908)
Ln (corr hk)*	−0.223*** (0.118)	−0.230* (0.072)	–	–	−0.871** (0.450)	−0.729** (0.369)	–	–
LnFDI	0.121* (0.019)	0.117* (0.017)	0.098* (0.016)	0.094*** (0.026)	0.114* (0.036)	0.166* (0.033)	0.118* (0.043)	0.126* (0.045)
LnPD	1.005* (0.329)	1.057* (0.271)	0.369** (0.179)	0.965*** (0.322)	0.431** (0.166)	0.456 0.387	0.728* (0.203)	0.826** (0.344)
LnGDPpa	0.376 (0.347)	0.486 (0.300)	0.039 (0.421)	0.627 (0.492)	3.129 (2.100)	0.866 2.248	2.338 (1.958)	0.398 (1.821)
GEE	−0.118* (0.039)	−0.118* (0.032)	−0.059*** (0.031)	−0.118** (0.048)	−0.314** (0.125)	−0.249 0.159	−0.251** (0.117)	−0.181 (0.159)
Pol2	0.0001 (0.001)	–	0.001 (0.001)	–	−0.021** (0.008)	–	−0.017* (0.006)	–
ECT(−1)	−1.243* (0.229)	−1.216* (0.228)	−1.046* (0.239)	−1.009* (0.276)	−1.247* (0.218)	−1.087* (0.307)	−1.214* (0.138)	−1.175* (0.231)
Short-run estimates								
LnGDP(−1)	7.025*** (1.863)	7.234*** (1.678)	1.969*** (0.546)	1.711*** (0.639)	4.677* (2.525)	0.928 (0.097)	1.807*** (0.594)	1.878* (1.022)
LnGDP(−2)	−2.335*** (0.685)	−2.441*** (0.649)	–	–	–	–	–	–
LnGDPPSQ(−1)	−3.516*** (0.931)	−3.621*** (0.838)	−0.986*** (0.273)	−0.857*** (0.319)	−2.348* (1.262)	−0.468 (0.491)	−0.910*** (0.303)	−0.936* (0.516)
LnGDPPSQ(−2)	1.167*** (0.342)	1.221*** (0.324)	0.002 (0.001)	–	–	–	–	–
Corruption	0.171** (0.086)	0.174*** (0.057)	–	–	0.706 (0.455)	0.438 (0.278)	–	–
Corr-PS	–	–	0.045 (0.028)	0.0518** (0.020)	–	–	−0.027 (0.065)	−0.065 (0.072)
Corr-NEG	–	–	−0.034 (0.021)	−0.044** (0.021)	–	–	0.144 (0.111)	0.055 (0.061)
Human Capital	−2.685** (1.124)	−1.621** (0.702)	−1.564** (0.738)	−1.436 (1.468)	−0.860 (3.260)	−2.891** (1.183)	2.396 (3.508)	3.246 (3.0001)
HKI2(−1)	−2.270*** (0.853)	−1.300*** (0.359)	–	–		–	–	–

Table 3 (continued)

Variables	Ln CO_2 per capita				Ln $S0_2$ per capita			
Specifications	ARDL		NARDL		ARDL		NARDL	
	With IQ	Without IQ	With IQ	Without IQ	With IQ	Without IQ	With IQ	Without IQ
Ln (corr hk)*	−0.277** (0.131)	−0.279*** (0.093)	–	–	−1.086 (0.762)	−0.793* (0.463)	–	–
LnFDI	0.078*** (0.014)	0.074*** (0.013)	0.058*** (0.014)	0.053*** (0.015)	0.142* (0.082)	0.180*** (0.064)	0.143** (0.059)	0.148** (0.062)
LnFDI(−1)	−0.037*** (0.012)	−0.035*** (0.010)	−0.039*** (0.012)	−0.037*** (0.011)	–	–	–	–
LnPD	1.250*** (0.361)	1.285*** (0.335)	0.386*** (0.138)	0.434*** (0.148)	1.273 (0.780)	0.496 (0.480)	0.884*** (0.291)	0.970* (0.510)
LnGDPpa	0.468 (0.397)	0.591* (0.339)	0.040 (0.435)	0.633 (0.423)	3.904* (2.272)	0.942 (2.550)	2.839 (2.547)	0.467 (2.184)
GEE	−0.079* (0.037)	−0.079*** (0.027)	−0.062** (0.026)	−0.067** (0.029)	−0.391* (0.158)	−0.271 (0.217)	−0.304* (0.158)	−0.212 (0.209)
Pol2	0.0001 (0.001)	–	0.001 (0.001)	–	−0.026*** (0.009)	–	−0.020** (0.008)	–
Bound test results								
F-statistic (k)	5.08 (6)	4.627 (6)	6.49 (5)	3.92 (7)	2.80 (7)	2.88 (7)	3.71 (7)	3.12 (7)
Critical value at 10% level	LB UB	LB UB	LB UB	LB UB	LB UB	LB UB	LB UB	LB UB
	2.12 3.23	2.12 3.23	2.26 3.35	2.03 3.13	2.03 3.13	2.03 3.13	2.03 3.13	2.03 3.13
Other diagnostic test results								
R^2	0.99	0.99	0.99	0.99	0.88	0.84	085	0.85
Serial Correlation LM Test-χ^2 (p-value)	0.000	0.000	0.000	0.007	0.033	0.264	0.034	0.104
F-test (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D-W test	2.555	2.588	2.548	2.26	2.18	2.19	2.226	2.187
Wald Test-p value	–	–	0.018	0.001	–	–	0.019	0.059
Normality test	0.895	0.913	0.873	0.311	0.000	0.000	0.000	0.000

i *, ** & *** indicates significance at level 10%, 5% & 1% level of significance, respectively

ii Standard errors are reported in parentheses

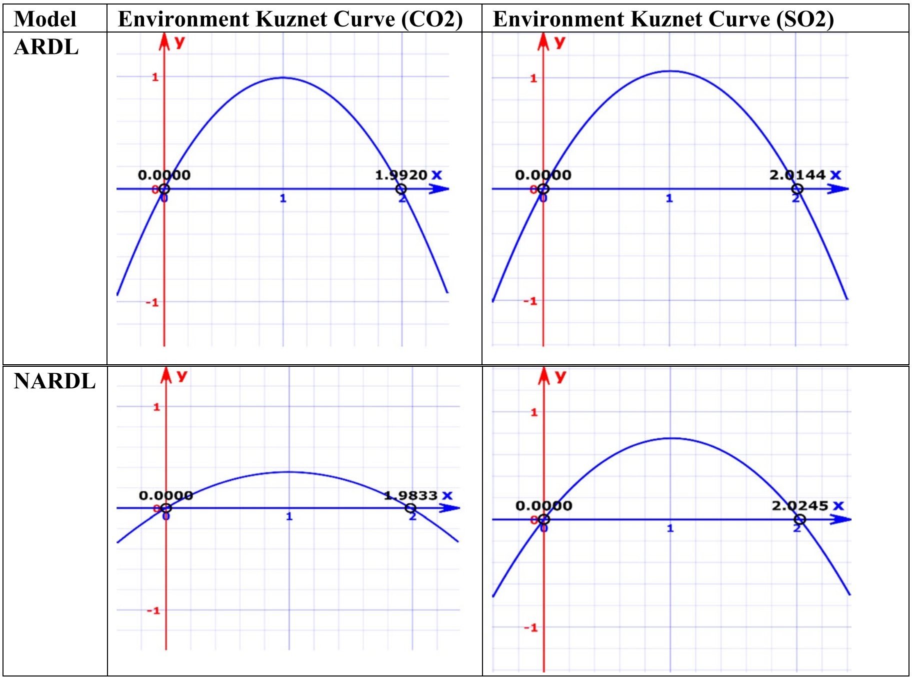

Fig. 2 Turning points *Source*:Author's computations

bound critical value, at 5% level of significance, in all equations and verifies the existence of long-run relationship among variables. Moreover, the error correction term is statistically negatively significant for all estimated equations and indicates the stability of the models. The other control variables display consistent findings across the estimated equations as well.

Turning to interpretation of results, a positively significant coefficient of corruption indicates that high corruption leads to increase in both types of emissions i.e., CO_2 and SO_2. While human capital possesses negatively significant effect on the polluted gases, throughout the regression equations. The interaction of corruption and human capital portrays the role of human capital as mitigating in environmental degradation-corruption relationship, as expected.

The effect of GDP and its square term is positive and negative on GHGs emission, respectively and support the existence of Environment Kuznets Curve hypothesis. It asserts that environmental degradation tends to increase with income until a certain threshold is reached, known as turning point, after that it begins to steadily decline resulting in inverted U-shape curve. This is due to three effects; scale effect when economic growth tends to increase pollution due to use of traditional technology. Composition effect where pollution increases when one sector in the economy grows relatively more than other sectors. Technique effect which tends to limit pollution at a certain (higher) level of economic growth enabling the country to use environment friendly and clean technology, the stage which is still awaited in case of Pakistan (Levinson & O'Brien, 2015). Alexianu (2019) rejected the idea that developing countries should focus on growth alone with the presumption that higher economic growth will take care of environment itself over time. Rather he asserted

Table 4 Environmental degradation and corruption (ARDL)

ED	CO2		SO2	
	Marginal effects	Total effect (%)	Marginal effects	Total effect (%)
Average HK (0.432)	0.042	9	0.189	37
10th percentile (0.265)	0.079	6	0.335	23
25th percentile (0.301)	0.071	7	0.304	26
50th percentile (0.418)	0.045	9	0.202	36
75th percentile (0.577)	0.009	12	0.063	50
90th percentile (0.584)	0.008	13	0.057	51

Source: Authors' computations from the estimated equations

that interventions in the form of environmental regulations and policy are required to play central role in minimizing environmental cost to economic growth. Policies can stimulate the technique effect by requiring polluters to adopt abatement technology even at the earlier stages of production and other than stimulating factors, human capital can play a profound role in this regard.

4.1 Turning points

Figure 2 further elucidates the findings on EKC and shows that environmental degradation increases with increase in GDP per capita, reaches its optimal point, and then turns to decline, based on equation $\beta_3 lnGDP_t + \beta_4 lnGDP_t^2$. The optimal point is about 1 percent while the value at which the effect is nullified stands around 2%.

4.2 Marginal effects of corruption on environmental degradation at various level of human capital

As the direct effect of corruption on environmental degradation is positive while holding human capital constant, the sign turns negative when corruption is interacted with human capital. Besides, the individual effect of human capital on environmental degradation is statistically significantly negative, as per our expectations. It shows that educated and well-informed population, termed as efficient human capital, tends to reduce environmental degradation through high productivity, innovations, awareness and the will to adopt environment-friendly production and consumption activities. The result is in line with Goetz et al. (1998), Zhang et al., (2021 and Çakar et al., (2021).

Since the effect of interaction term is not directly observable, a conditional interpretation through marginal effect of corruption on environmental degradation is computed at the average value of human capital. In order to get further insight and to delineate the offsetting role of human capital in corruption and environmental degradation relationship, marginal effects are computed for the range of percentiles (10th to 90th) of human capital, following Brambor et al., (2006). Table 4 presents the marginal and total effect of corruption for both types of emissions and at various levels of human capital. The reported results are based on ARDL equations for CO_2 & SO_2 (with IQ) and shows the effect of corruption on environmental degradation is declining significantly at successively higher level of human capital. It demonstrates a slip from 6 to 13%. Similarly, at the average level of human capital (0.432), the effect tends to reduce by 10%.[11] The findings are in line with literature (Goetz et al., 1998; Saleem and Shujah-ur-Rahman 2019; Zhang et al., 2021; Çakar et al., 2021; Çamkaya et al., 2022). The findings are further elucidated by Figs. 3 and 4, which present declining environment degradation as a result of corruption at successively higher level of human capital.

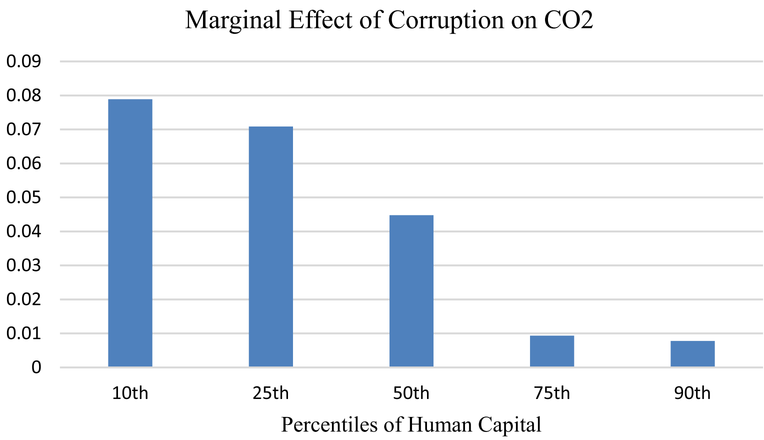

Fig. 3 Marginal effects of corruption on CO_2 (at various percentiles of HK). *Source*: Authors' computations

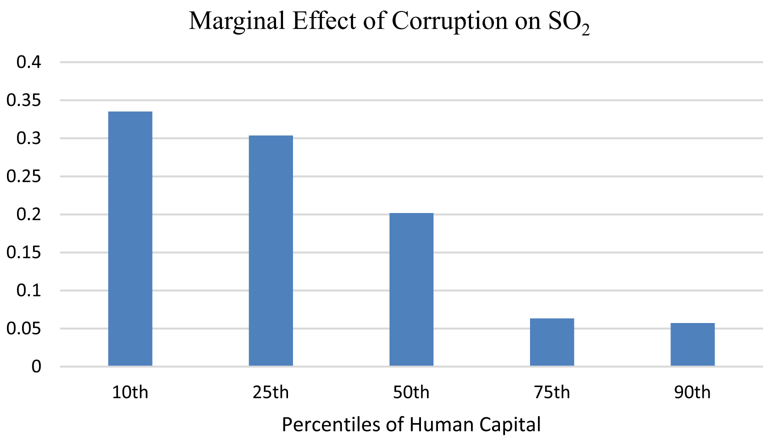

Fig. 4 Marginal effects of corruption on SO_2 (at various percentiles of HK). *Source*: Authors' computations

[11] $LnED_t = \beta_0 + \beta_1 Corr_t + \beta_2 \ln HKI_t + \beta_3 \ln \left(Corr_t * HKI_t \right)$

$\frac{\partial \ln ED_t}{\partial Corr_t} = \beta_1 + \beta_3 hk$

4.3 Asymmetric effects of corruption on environmental degradation

The NARDL results of corruption on environmental degradation, reported in Table 3, justifies the proposition of asymmetric effect of corruption on CO_2 emission. As mentioned earlier, Wald test shows that positive shocks in corruption display statistically significantly different impact on environmental degradation from the negative shocks. The findings show that positive shocks in corruption is disposed to deteriorate environmental quality, both in the short and long run, while negative shocks tend to improve the environment. The effect of positive shocks in corruption is particularly pronounced and significant for the model where we did not control institutional quality. Conversely, the effect tends to reduce in the presence of institutional quality. This implies that absence of institutional quality leads the producers' choice in selecting sub-optimal and environment unfriendly technologies that leads to environmental degradation. However, when institutional quality is controlled it leaves the choice to citizens and urges producers, through consumers' pressure, to use such technology and production practices that are environment friendly. The findings are in line with Odugbesan and Adebayo (2020) and Khan and Yahong (2021), for the asymmetric effect on CO_2 emission of the variables of choice. However, the results of both shocks for SO_2 emission are statistically insignificant.

4.3.1 Other Control Variables

FDI appears to have adverse environmental impact both in the short-and long run, with and without controlling IQ. The result indicates that the country has been treated as pollution heaven by the Multinational Corporations (MNCs) who are inclined to transferring dirty industrial practices due to weak environmental regulations in the country and also because the developing countries like Pakistan relax the environmental standards to attract foreign investment (Arif et. al., 2022; Javorcik & Wei, 2004; Asghari, 2013; Ray & Sarbapriya, 2011; Golub et al., 2011). Another variable population density also tends to increase GHGs emissions as the population pressure diffuses more consumption and carbon emission hereof. Moreover, urbanization become a bulge with high population density and urges the extensive use of agricultural land and scare resources. These factors ultimately upsurge the environmental degradation. The result is consistent with the findings of Ray and Sarbapriya (2011). Besides, government expenditures on education reduce both types of gases emissions, as the investment on research and development complement the human capital and leads towards improvement in environment quality.

5 Conclusions and policy implications

This study investigates the effect of corruption on environmental degradation in Pakistan for time period 1980–2020. The direct and moderating role of human capital on environmental degradation, measured as emissions of CO_2 and SO_2, is also examined. The Autoregressive Distributed lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models are employed to estimate the linear and asymmetric effect of corruption, respectively. The findings show that corruption tends to increase environmental degradation while, human capital reduces the greenhouse gases emissions significantly. Furthermore, significant interaction term of human capital with corruption indicates the moderating role of human capital on corruption and GHGs emission relationship. The asymmetric effect of corruption on CO_2 emission, via positive and negative shocks, is statistically significant both in the short- and long run and shows that positive change in corruption increases while negative change decreases CO_2 emissions significantly. The study also proves the existence of EKC in Pakistan and display turning point as well. Among other control variables, FDI and population density have deteriorating while, government expenditure on education has stimulating role in GHGs emissions.

The empirical findings enable us to establish that corruption tends to damage environmental quality. A strict accountability and good governance is required to handle the issue of corruption. To promote low-GHGs emitting technologies, sound institutional set up with quality governance and rule of law can play supportive role. Moreover, human capital has proved significant in improving environment and directing environment policy into right direction, we need to promote our existing human capital through education and training. More specifically, there is a dire need to infuse the concept of environmental education in our education system. The expenditures on education need to be increased and the resources should be directed to the productive use. Furthermore, FDI should be encouraged in greener technology projects by offering attractive initiatives.

6 Limitations of the study and directions for future research

The study has attempted new directions in research, however it is not exhaustive. The new insights can be provided by extending this research, from a case study to a regional study where cross-country comparison can be made to find out the direct and indirect effect of human capital on the corruption and environment relationship. This would enable respective countries to understand their position with reference to policies, rules and regulations, both for the control of corruption and environmental degradation. That would also identify the required level of human capital in offsetting the effects of corruption and hence, environmental degradation. This would further help them determining their nationally determined contribution for environment protection.

Author Contributions BY conducted the analytical work, estimation and write up of the paper. RB collected data and conducted review of literature and edited few sections of discussion of results and conclusions.

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Data availability The datasets generated during and/or analysed during the current study are available in the World Development Indictor, Regional Emission Inventory in Asia, Penn World Table & ICRG.

Declarations

Conflict of interest The authors declare no competing interest.

Consent for publication Not applicable.

Ethics approval Not applicable.

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