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Abstract

In recent decades, there has been an increase in weather and climatic extremes that cause natural disasters. Such occurrences, along with socioeconomic shifts that heighten their exposure and raise the possibility of maladaptation, are hindering the economic and social growth of developing nations. This study aims to examine the impact of climate change on sustainable development at the district level in Pakistan by estimating the overall results using OLS regression, system GMM, and quantile regression. The period span of the study is from 2004 to 2019. The main objective of the study is to construct the sustainable development index (SDI) and the inequality-adjusted sustainable development index (ISDI). The study's hypothesis that climate change has a negative impact on sustainable development is supported by the findings. The results indicate that precipitation and maximum temperatures and sex ratio have negatively significant impact on sustainable development while wind speed shows inconsistency in the results. However, the minimum temperature is showing positive and significant impact on sustainable development. On the other hand, the dependency ratio and household size vary in estimation as both variables have complex and multifaceted relationship with sustainable development. The ICT has both negative and positive impacts on sustainable development but on average the overall impact of ICT is positive and significant. Ownership of assets also have positive and significant impact on sustainable development. The study suggests that Pakistan should introduce safe modes of energy to reduce the impact of greenhouse gas emissions. Districts should adopt policies that are suitable for them according to their area like districts having more severe temperature should use solar energy. On the other hand, through the use of green infrastructure solutions including rain gardens, permeable pavement, and green roofs, floods can be control for the districts facing heavy rainfalls.

1. Introduction

Climate change is the most pressing challenge and a significant threat to the sustainability and inclusiveness of societies, as well as the habitability of our planet (Bhattacharya et al., 2021). Its causes stem from a combination of factors identified as early as the 19th century (Fourier, 1824; Tyndall, 1861; Arrhenius, 1896), with rising greenhouse gas (GHG) emissions driven by economic activity being the primary contributor. Since 1960, the global economy has expanded at an average annual rate of 3.5%, while carbon dioxide emissions have grown by approximately 2.5% per year. Despite an average global GDP growth of around 1% annually, the persistent increase in emissions, coupled with the planet's limited capacity to absorb carbon dioxide, has resulted in an unprecedented atmospheric concentration of the gas. By 2020, carbon dioxide levels reached 417 parts per million (ppm), a stark rise from 278 ppm before the Industrial Revolution in 1750 (WMO, 2019).

The risks and costs associated with climate change have consistently been underestimated. Its adverse effects disproportionately impact the poor, as they have fewer resources to adapt and are more vulnerable to both immediate shocks and long-term consequences. Without effective mitigation, climate change could displace tens of millions of people, particularly in low-income countries. Moreover, reliance on carbon-intensive economic growth threatens future employment, as industries reliant on fossil fuels will eventually need to be phased out to prevent catastrophic climate consequences. Delays in decarbonization will only make the transition more disruptive, leading to severe shocks in high-emission sectors. This could result in a significant loss of wealth, income, and jobs, pushing millions into poverty (Cerra et al., 2021).

Sustainable development is broadly defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." While the concept can be interpreted in various ways, its core principle is a balanced approach to development that integrates environmental, social, and economic objectives within the constraints of our planet's resources (SDC, 2011). Despite the growing urgency of climate change, many developing nations have yet to prioritize their sustainability policies. Concurrently, research also showed that these countries are among the most vulnerable to climate change, as their populations face greater exposure to climate-related risks and have limited capacity to adapt. Moreover, climate change threatens their long-term development prospects by exacerbating economic instability and environmental degradation.

Climate change is deeply intertwined with various subdimensions of sustainable development, reflecting the interconnected nature of environmental, social, and economic systems. For instance, climate change is inextricably linked with the environmental dimension of sustainable development. Along with its detrimental long-term impact on biodiversity, ecosystems, and natural resources, climate change has an immediate impact on environmental sustainability (Shivanna, 2022). Habitat loss and species extinction are triggered by ecosystem disturbances caused by rising temperatures, fluctuating patterns of precipitation, and extreme weather events.

Similarly, social inequalities and disparities are made worse by climate change, which disproportionately affects vulnerable groups including the underprivileged and marginalized (Gunby & Coupe, 2021). Climate change poses economic hazards such as increased healthcare costs, job losses, and damage to infrastructure. Climate change worsens poverty and inequality and causes significant socioeconomic damage, even for moderate temperature rises. The major impact routes are disruption of agriculture, decreased labor productivity, damage from natural disasters, and rise in sea level (Munasighe 2010).

The lack of climate policy action in the sustainability assessments of developing countries corresponds with the limited empirical research on the impact of climate change on sustainable development in these nations, despite the well-established link between the two. The research gap is even more pronounced when examining the issue at the household level. Given this scarcity of research, this study has three primary objectives. First, it aims to analyze the impact of climate change on sustainable development at the household level. To achieve this, the study constructs an 'outcome-based' sustainable development index, incorporating household status across social, economic, and environmental dimensions. Second, it seeks to assess the effects of climate change on inequality-adjusted sustainable development, recognizing that climate change has disproportionate redistribution effects, often exacerbating inequalities. Third, the study examines the impact of climate change across different quantiles of sustainable development to capture potential variations in its effects across different levels of sustainability.

This study makes several significant contributions to the existing literature on climate change and sustainable development, particularly in the context of developing countries. While much of the existing research focuses on macroeconomic or national-level impacts, this study shifts the focus to the household level, providing a more granular understanding of how climate change influences sustainable development at the microeconomic scale. Studies major contribution lies in the construction of 'outcome-based' sustainable development index and offers a comprehensive framework that integrates social, economic, and environmental dimensions, filling a critical gap in empirical research. The study moves beyond conventional sustainability measures by incorporating inequality-adjusted metrics. Recognizing that climate change has redistributive effects, it examines how climate change disproportionately affect vulnerable populations, thereby worsening socioeconomic disparities. This approach provides novel insights into the intersection of climate change, inequality, and sustainability, which has been largely overlooked in previous research. Moreover, unlike traditional studies that rely on mean-based estimations, this research employs quantile regression techniques to explore how climate change impacts sustainable development across different levels of sustainability. By capturing heterogeneous effects, the study highlights variations in climate impact across households with different sustainability outcomes, offering a more nuanced understanding of the issue.

The study is conducted for Pakistan which is one of the most climate-vulnerable countries in the world, despite contributing less than 1% to GHG emissions. The country ranks among the top 10 most affected nations in the Global Climate Risk Index due to its exposure to extreme weather events, including heatwaves, floods, droughts, and glacial melt. Similarly, As of the latest available data, Pakistan faces significant challenges in achieving the Sustainable Development Goals (SDGs). According to the Sustainable Development Report 2024, which assesses the progress of all 193 UN member states towards the 17 SDGs. Pakistan has an overall SDG Index score of 56.2 out of 100, indicating that the country is approximately 56.2% of the way towards achieving the SDGs. Pakistan ranks 134th out of 193 countries in terms of SDG performance. The report highlights that Pakistan has made progress in areas such as poverty reduction (SDG 1) and access to health services (SDG 3). However, significant challenges remain in achieving goals related to quality education (SDG 4), gender equality (SDG 5), and climate action (SDG 13).

Given that climate change policies in many developing nations remain underdeveloped, this study provides empirical evidence that can inform policy decisions. By identifying key channels through which climate change affects sustainability at the household level, it offers actionable insights for policymakers to design more targeted and equitable climate adaptation strategies. Overall, this study advances the literature by integrating micro-level analysis, inequality considerations, and quantile-based assessment, thereby offering a more comprehensive understanding of how climate change influences sustainable development in developing nations.

2. Literature Review

The body of literature investigating the relationship between climate change and sustainable development is still in its early stages. Research addressing this issue at the micro level remains limited. Therefore, in this study, we review existing literature that explores the connection between climate change and various dimensions of sustainable development at household level.

The impact of climate change on household sustainable development is profound, affecting economic resilience, food security, and overall quality of life. Households, particularly in developing nations, face increased risks due to climate variability, which exacerbates poverty and limits adaptive capacity. Gai, Lin and Zhang (2024) examined the impact of daily temperature variations on rural income per capita and evaluated the effectiveness of adaptation based on China's county-level socioeconomic statistics and household survey data. The findings showed that high temperatures have significant negative effects on rural income per capita. Evidence from micro-data indicates that agricultural income of rural households is sensitive to high temperatures relative to other components of household income, such as wage income and transfer income, which leads to a reallocation of rural laborers across sectors.

Li, Lui and Lu (2024) examined the impact of climate change on household development resilience in rural China, using longitudinal data from 1989-2015. The results of the study showed that climate change leads to reduced agricultural productivity, which is crucial for household income, particularly in rural areas. It is also observed that increased economic volatility and consumption risks associated with climate change diminish upward mobility for households. Nonetheless, climate adaptation mitigates household welfare loss to a greater extent through agricultural input adjustments and income diversification in the long run.

Nema and Muthupriya (2022) showed that climate change impacts household sustainable development by increasing food insecurity, poverty, and health risks, while causing displacement and loss of livelihoods. Vulnerable families struggle to adapt due to limited resources, hindering their ability to achieve sustainable development goals. Nonetheless the study showed that developing nations have dire need for more research and data on how climate change and extreme weather affect families and communities. This problem of lack of research must be addressed to ensure that sustainable solutions can be implemented.

Akpoduado & Boyitie (2024) assessed household perception of climate change on economic activities in Ughelli North Local Government Area of Delta State. Results obtained showed that households in the area were knowledgeable of climate change. The study revealed that households' perceived changes in economic activities to include decreasing working hours engaged in economic activities, decrease in food crop farming/fish farming, drastic changes in principal sources of income and livelihood, changes in crop yields and productivity and changes in availability of fodder and non-timber forest product as well as decrease in workforce productivity. Based on the findings, the study recommended that the government should encourage soft loans to farmers and fish farmers. This will ensure the steady supply of food, thereby increasing households' source of livelihood and nutrition.

Brzezinska and Jasper (2024) found that temperature variability negatively affects household wealth in low- and middle-income countries, with the most significant impacts observed in Sub-Saharan Africa, low-income countries, and tropical climates, threatening progress in poverty reduction and economic stability. Similarly, Bakhsh, Naqvi and Nasim (2022) showed that climate change adversely affects agricultural income, which is crucial for rural households. This impact leads to resource reallocation from health, education, and consumption towards adaptation strategies, ultimately deteriorating the socioeconomic conditions of farm and landless households.

Pavlovic et al. (2021) empirically examined the impact of changing climate on long term development in the case of Vojvodina. The study summarizes the 50-year (1950-2006) annual and monthly air temperature and rainfall fluctuations in Vojvodina's Province using a linear tendency estimation and a statistical approach for climatic trends. From the assessment of the findings of yearly average flow trends, it is concluded that the region of Vojvodina is experiencing the influence of climate changes, which are considerably altering and modifying the province's socioeconomic strategy.

Tosam and Mbih (2015) critically explained the impact of climate change on health and sustainable development in the African continent. The study reveals that despite being contributing to a small portion of global climate change, Africa is the world's most vulnerable continent to climate change, which destroys human sources of nourishment, medication, living conditions, and income, resulting in poor nutrition and increased vulnerability to infectious illnesses, more hospitalizations, fewer working hours, and significant economic damage. The paper concluded that the good governance, advancement of African traditional values that promote environmental protection, a focus on rural development and the economic and political independence of women, and investments in alternative and green energy are all essential prerequisites for efficiently mitigating the impacts of climate change and implementing sustainable development in Africa.

The brief review of literature showed that **the** existing literature on the impact of climate change on household sustainable development has primarily focused on isolated dimensions—economic, social, or environmental—without integrating them into a comprehensive framework. This fragmented approach limits a comprehensive understanding of how climate change affects overall household sustainable development. Our study aims to bridge this gap by constructing an 'outcome-based' sustainable development index that integrates economic, social, and environmental indicators. This comprehensive framework will allow for a more nuanced analysis of climate change's effects on household sustainable development, capturing the multidimensional vulnerabilities that households face. Furthermore, our research will examine the inequality-adjusted impact of climate change on sustainable development, considering how its effects vary across different socioeconomic groups. Additionally, by employing quantile-based analysis, we will assess how the impact of climate change differs across varying levels of household sustainability.

3. Methodology

3.1. Model Specification

The general form of the model is given as follows

$$\boldsymbol{SDI_{it} = f(\,Temp_{it}, Pre_{it}\,, Ws_{it}, Dr_{it}, HHp_{it}, OA_{it}, ICT_{it}, HS_{it})} \quad \textbf{(1)}$$

Where SDI is dependent variable, Temp, Pre, Ws, are focused variables and HHp, Dr, OA, ICT, HS are controlled variables. For ISDI, the same functional form is taken into account.

Empirical models:

$$\boldsymbol{SDI_{it} = \alpha + \alpha_1 \mathrm{Temp}_{it} + \alpha_2 \mathrm{PRE}_{it} + \alpha_3 \mathrm{WS}_{it} + \alpha_4 \mathrm{DR}_{it} + \alpha_5 HHP_i + \alpha_6 OA_{it} + \alpha_{17} ICT_{it} + \alpha_8 HS_{it} + \alpha_9 SR_{it} + \mu_{it}} \quad \textbf{(2)}$$

$$\boldsymbol{ISDI_{it} = \beta + \beta_1 \mathrm{Temp}_{it} + \beta_2 \mathrm{PRE}_{it} + \beta_3 \mathrm{WS}_{it} + \beta_4 \mathrm{DR}_{it} + \beta_5 HHP_i + \beta_6 OA_{it} + \beta_{17} ICT_{it} + \beta_8 HS_{it} + \beta_9 SR_{it} + \omega_{it}} \quad \textbf{(3)}$$

Note: i represents districts and t represents time period

SDI= Sustainable development index

ISDI= Inequality-adjusted SDI

Temp= Temperature (min, max and average temperature)

Pre= Precipitation

WS= Wind Speed

DR= Dependency ratio

HHP= Households province $(\mathrm{HHPd}_1 = (\text{if Punjab} = 1 \text{ otherwise } 0)\,, \mathrm{HHPd}_2 = (\text{if Sindh} = 1 \text{ otherwise } 0), \mathrm{HHPd}_3 = (\text{if KPK} = 1\text{otherwise } 0)\,, \mathrm{HHPd}_4 = (\text{if Balochistan} = 1 \text{ otherwise } 0))$

OA= Ownership of assets

ICT= Information and Communication technology

HS= Household size

SR= Sex ratio

3.2. Data Sources and Construction of Variables

The study uses microdata from Pakistan's Social and Living Standard Measurement (PSLM) Surveys, conducted between 2004 and 2019 for its empirical research. The Pakistan Bureau of Statistics began conducting this survey at the provincial and district levels in 2004. Establishing comprehensive social and economic indicators in order to attain the Sustainable Development Goals (SDGs) and the Millennium Development Goals (MDGs) is the key objective of PSLM. On behalf of the Pakistani government, the Federal Bureau of Statistics conducts the household survey. It gives accurate and detailed information on variables associated with households. This survey contains enough of a sample to generate precise and consistent results. The data is collected from several districts, encompassing both urban and rural areas, dispersed throughout Pakistan's four provinces; (Punjab, KPK, Sindh, and Baluchistan) covering 79 districts over a period of seven years, described in table 1

Table 1: Data Composition

Years	Districts	Households
2004-2005	79	14,744
2005-2006	79	15,453
2007-2008	79	107,207
2010-2011	79	108,933
2013-2014	79	119,343
2015-2016	79	157,775
2018-2019	79	159,949

Household demographics, income, health, assets, spending, and other socioeconomic aspects are all incorporated into the information. The dependency ratio and household's region (by creating dummy, 0=urban otherwise rural), household's province (by creating 4 dummies for all provinces), ownership of assets (OA) and information and communication technology (ICT) are taken as controlled variable. The details of dependency ratio, ownerships of assets and ICT are as under in the table 4.2.

Table 2: Controlled variables	
Dependency ratio	Employment dependency ratio, age dependency ratio, sex ratio
Ownership of assets	Ownership of agriculture land Ownership of non-agriculture land Ownership of residential building Ownership of commercial land or non-residential building
Information and communication technology	Television, radio, video player, internet, personal computer, laptop etc.

The study's data for climate change was compiled from 2004 to 2019 from NASA by putting values of longitudes and latitudes for each district, While PSLM-HISE is the source of data for all other variables.

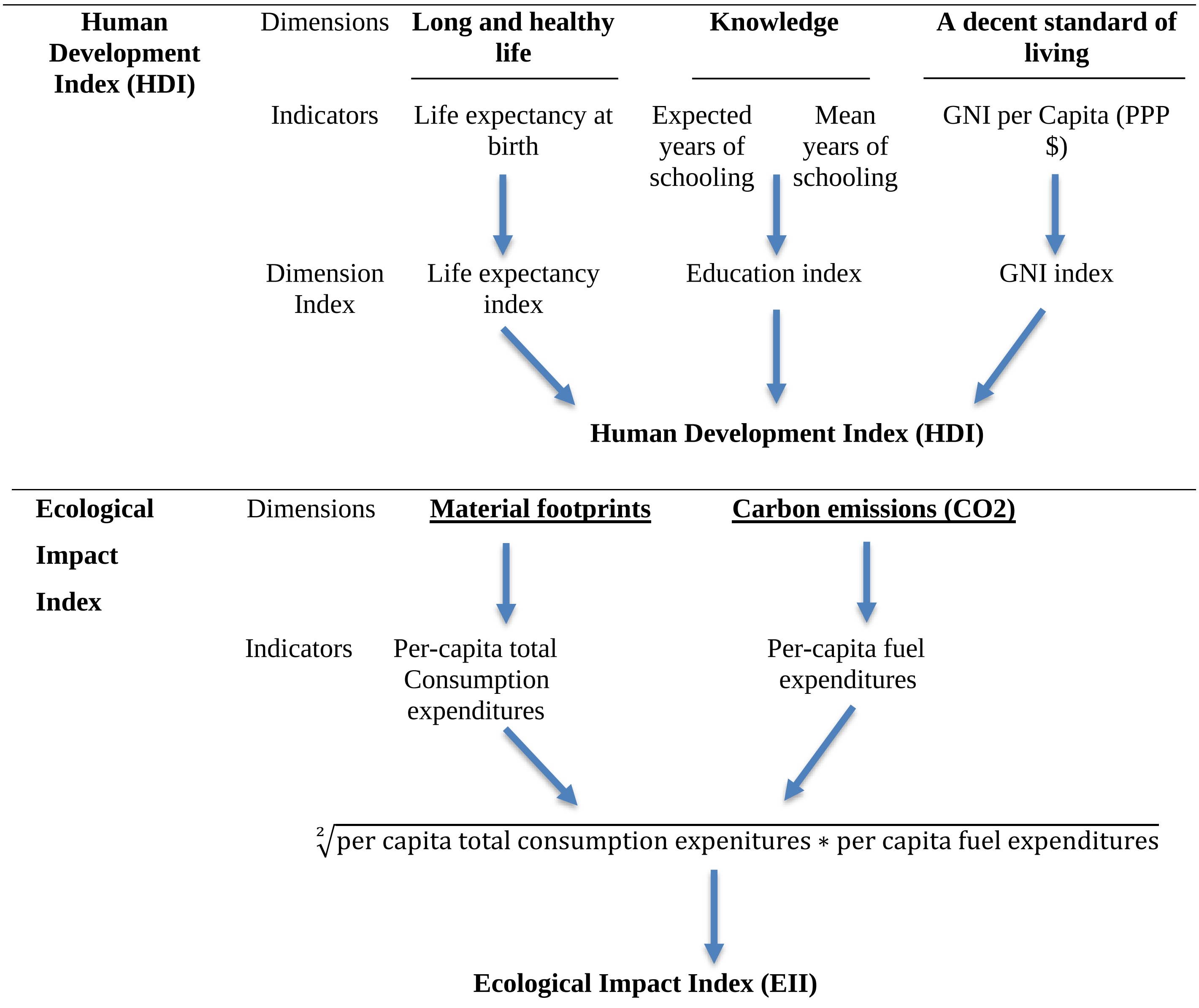
3.3. Construction of Indices

The objective of this study is to investigate the effects of climate change on SDI, ISDI and to perform geographical comparisons based on regions, districts, and provinces. It is the first empirical study to compute SDI and ISDI for Pakistan at the district level.

For this purpose, we adopted Hickel (2020) approach to construct outcome-bases SDI. The SDI is originally computed by dividing two numbers: (1) a "development index," which originates from the Human Development Index (HDI) and is based on the geometric mean of the life expectancy, education, and modified income indices; and (2) a "ecological impact index," which is derived from the measurement of the difference between the per-capita shares of planetary boundaries and consumption-based CO2 emissions and material footprint (Hikel,2020).

The initial and most important indicator for estimating sustainable development is the HDI, which is based on the accomplishments of Amartya Sen on human potential and Dr. Mahboob-ul-Haq on inequality. Since improving quality of life is the key objective of development activities, indicators like GDP are not an accurate measure of an economy's sustainable development (Nordhaus and Tobin, 1973; Stiglitz et al., 2009).

Figure 1: Human Development Index and Ecological Impact Index



Source: Authors Construction

It is made up of three dimensions: standard of living, long and healthy life, and knowledge, as shown in Figure 1. Every dimension has a distinctive variable. The two variables "average years of schooling for 25 years and above" and "expected years of schooling of school going age" are employed to measure the education dimension. The period of time spent in school at each educational level defines the average total number of years completed in school. On the other hand, "enrollment by age across all levels of education" and "number of children of who are in school in the population as a whole for each stage of education" are two more metrics used to assess projected years of schooling. The term "life expectancy at birth" is used to measure the health factor. As a substitute for the standard of living dimension, the "log of Gross National Income (GNI) per capita is employed (UNDP, 2010, p. 223-224).

The term "ecological impact" describes how human activity affects ecosystems and the environment. These impacts are evaluated and measured using a variety of techniques and metrics. In our study we took per capita total consumption expenditures of households and per capita fuel expenditures to calculate EII. However, these are the proxies for material footprints and carbon emissions. As per methodology of Hickle (2020) EII is computed by average overshoot (AO), which is further discussed in this chapter.

Table 3: Human Development Index values

Dimensions	Indicators	Min	Max
Health	Life expectancy at birth (years)	20	85
Education	Expected years of schooling (years)	0	18
	Mean years of schooling (years)	0	15
Standard of Living	GNI per capita (2017 PPP$)	100	75,000

There are minimum and maximum index values specific to each dimension (Table 3). Because no country has been shown to have a life expectancy at birth of less than 20 years, the minimum life expectancy at birth in the health dimension is predicted to be 20 years (Oeppen and Vaupel 2002; Riley 2005). On the other hand, the maximum years of lifespan is established at 85 based on data gathered over the last three decades for numerous countries.

$$\text{Life expectancy index} = \frac{LE-20}{85-20} \qquad \ldots \qquad (1.1)$$

The Mean Years of Schooling Index (MYSI) in the education index is measured as MYS / 15. The expected maximum for 2025 is 15 years of education, which stands for the maximum value. A minimum of zero years of schooling is required. EYS / 18 is the Expected Years of Schooling Index (EYSI). The maximum worth is 18 years of education, which is approximately equal to a master's degree in most of the nations. A minimum of zero years of education is expected (Hickel and J, 2020).

$$\text{Education index} = \frac{MYS+EYS}{2} \qquad \ldots \qquad (1.2)$$

The income dimension has a fixed minimum value of \$100 per capita and an assumed maximum value of \$75,000 per capita. The study by Kahneman and Deaton (2010), which found that economies with per capita incomes higher than \$75,000 are unable to produce any advances in terms of their well-being and human development, provided support for setting the maximum per capita value at \$75,000. To estimate the income index, we took log of per capita income of households.

$$\text{Income index} = \log(\text{GNI pc})$$

The following is a discussion of how each dimension index is calculated:

$$Dimension\ Index\ = \frac{\textit{Actual value - Minimum value}}{\textit{Maximum value - Minimum value}} \qquad \ldots \qquad (1.3)$$

The HDI is the geometric mean of three indices:

$$HDI\ =\ \sqrt[3]{\textit{(Life expectancy index) * (Education index) * (Income index)}} \ldots \qquad (1.4)$$

Or

$$HDI\ =\ \sqrt[3]{(I^{*}_{Health}) * (I^{*}_{Education}) * (I^{*}_{Income})} \qquad \ldots \qquad (1.5)$$

The average rate of return and redistribution of a set of values in equal ratios determined by their product is known as the geometric mean. This method has been found to be highly beneficial in the disciplines of finance and economics for addressing variables like investment, growing markets, rising populations, and other growth-related aspects (Holmes et.al, 2017).

The United Nations Development Report (UNDP) methodology explains that the formulation of the HDI is based on the macro level. In the present case, the UNDP approach was employed to evaluate the HDI at the district level. By subtracting the maximum age of the household from the maximum age of the distribution, the factor of life expectancy has been measured. According to a

UNDP report, the education aspect has also been measured by considering the mean and expected number of years of schooling for every household. The average household income is used to measure the income dimension. Each of the three dimensions have been estimated at the household level by averaging individuals.

Additionally, a scaling of 0 to 1 indicating the maximum to minimum value of each index in the data set has been made to all three indices. The following formula has been used to normalize the data.

$$X_{normalized} = \frac{(X\text{-}X_{minimun})}{X_{maximum} - X_{minimum}} \quad \ldots \quad (1.6)$$

The process of normalization involves converting the data into a minimum and maximum value between 0 and 1. In order to prevent bias among variables, this approach tends to be employed on multivariate datasets that have different variances (Asesh and A,2022).

The following is a description of the ecological impact index:

As per methodology of Hickle (2020), Ecological Impact Index is calculated by Average Overshoot (AO).

$$\text{AO} = \sqrt[2]{\left(\frac{MF}{boundary} \geq 1\right) * \left(\frac{CO2}{boundary} \geq 1\right)} \quad \ldots \quad (1.7)$$

This is how average overshoot (AO) is computed. To calculate the amount of boundary overshoot (or undershoot), the material footprint (MF) and emissions (CO2) numbers are divided by the corresponding per capita planetary boundary, which fluctuates annually based on population size. Additionally, this integrates the units. The result of either division is expressed as 1 if it is less than 1 (undershoot). The geometric mean is then used to average the findings. This approach guarantees that a nation cannot undershoot one limit in order to make up for overshooting the other. An average overtaken of more than one will result from exceeding either barrier (Hickel, 2020).

However, as we lack direct access to local material footprint and carbon emissions data, we in our case compute the ecological impact index (EII) using per capita fuel expenditures for carbon emissions and per capita total consumption expenditures of each household for material footprint as a proxy.

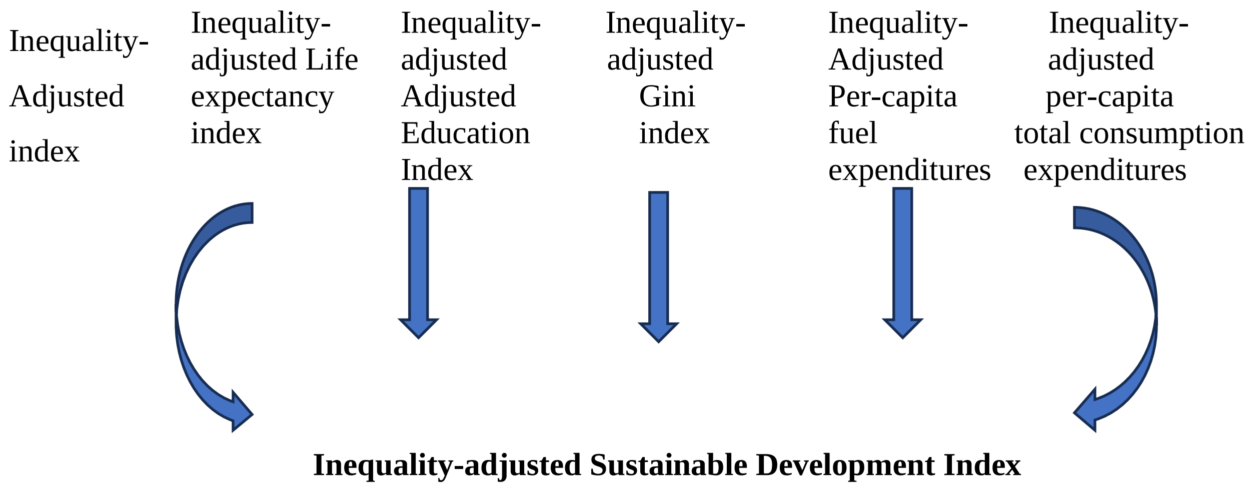
The same equation has also been used to normalize the variables for material footprints and carbon emissions into a scale of 0 to 1.

$$X_{normalized} = \frac{(X\text{-}X_{minimun})}{X_{maximum} - X_{minimum}} \quad \ldots \qquad (1.8)$$

Atkinson's inequality measure, often known as the Atkinson index, is used to calculate the ISDI. This index is usually used to measure the disparities in how each dimension is distributed among the population. The Atkinson index is a welfare-based metric, according to the United States Census Bureau (2021). The aversion parameter (Ɛ) in the Atkinson inequality measure is set to 1. A= 1-g/μ is the formula to compute inequality, where the arithmetic mean of the distribution is represented by μ in this expression, while the geometric mean is denoted by g. The averages of the distributions that are important for computing inequality are found using the Atkinson index. The Atkinson inequality metric estimates the percentage of total income that a country must give up to achieve equal income shares among its citizens. Atkinson measures rely on research estimation for their degree of inequality measuring parameter.

Figure 2: Inequality-adjusted Sustainable Development Index

ISDI	Dimensions	**Life expectancy index**	**Education index**	**Gini index**	**Per-capita fuel expenditures**	**per-capita total consumption expenditures**



As illustrated in figure 2, we use the Atkinson index of inequality to compute the inequality-adjusted index for each of the SDI's dimensions in order to estimate the ISDI. We determine each inequality index value using Atkinson, which is represented by Ix. then we obtain the value of the aversion parameter (A2) and use the command to construct the inequality index by multiplying each index by (1-Ax), where Ax is the Atkinson value for the inequality.

Health, education, and transportation expenditures are used for the total consumption expenditures (proxy for material footprints) and fuel expenditures are taken to calculate the carbon emissions from the household expenditures portions of the PSLM-HIES's questionnaire. The lists the specific items that are included in the expenditures of our variables of interest for the Ecological Impact Index (EII) are attached in appendix.

As large database analyses are frequently challenging to interpret. Therefore, by splitting the variance of every variable in its corresponding sub-index, Principal component analysis (PCA) is one of the most reliable and efficient techniques to handle huge sets of variables (Gwartney and Lawson, 2001; Gaydos et al., 2013). By generating new uncorrelated variables, it decreases the overall dimension of datasets and improves interpretability. Moreover, it maintains the highest degree of variety without sacrificing the provided statistical data (Jolliffe et al, 2016). The current study applied Principal component analysis (PCA) on the 3 variables; (HDI, per capita fuel expenditures and per capita total consumption expenditures) to compute SDI (SDI). In order to calculate the ISDI, we used PCA on the three previously described dimensions of SDI as well as on household total consumption expenditures and per capita fuel expenditures.

On the other hand, high values of variables such as per capita fuel expenditures and per capita total consumption expenditures under the SDI indicate a negative impact of sustainable development. Therefore, using the same normalization procedure, these variables have been reversed.

3.4. Estimation Techniques

Due to the panel data model used in this investigation, we employ the two-step system GMM methodology, developed by Arellano and Bond (1991). This general estimator is designed to be used in conditions where there are "small T, large N" panels, which demonstrate a large number of individuals over a short period of time, non-exogenous independent variables that are correlated with past and possibly current realizations of the error, fixed effects, and heteroskedasticity and autocorrelation within individuals (Roodman 2009). This approach is justified by the fact that the typical fixed effects estimator takes into consideration the potential endogeneity of certain of the dependent variables and is biased when the lagged dependent variable is used as a regressor (Silva et al, 2017). The study used System-GMM to address the endogeneity problems as variables of SDI and climate change are interlinked.

When two consistent estimators with different levels of efficiency exist under the null hypothesis and the two estimators produce different results under the alternative hypothesis of misspecification, a Hausman test (Hausman, 1978) can be used. For statistical discrepancies between the fixed effects and random effects estimations, we consider this kind of test.

In order to overcome the limitations of existing statistical techniques or accommodate new research requirements, newer procedures generally get established. In order to address some of the drawbacks of least squares mean regression (LMR), a relatively new methodology termed as quantile regression (QR) is employed in this study. When the homoskedasticity and normality assumptions are broken, QR is a better fit. When the research literature indicates that investigations into the relationships between variables should shift from concentrating on average performance, or the central tendency, to examining different points along the entire distribution, QR has also been suggested as a good substitute (Chen et al, 2014).

Certain traditional quantile estimation techniques suffer from bias effects similar to those in the OLS scenario when the time dimension is minimal when lagged dependent variables are included in a quantile panel data model with fixed effects. In this instance, we employ the instrumental variables (IVs) quantile regression approach using lagged regressors as instruments, which reduces the dynamic bias in the quantile regression fixed-effects estimator (Tian et al, 2018).

4. Results and Discussions

This study's goal is to ascertain the climate change-related factors, such as precipitation, wind speed, and temperature, that significantly affect the SDI via empirical analysis. This section includes the empirical findings we estimated for the model analyzing the impact of climate change on sustainable development in Pakistan a district-level analysis. To choose between random or fixed effects regression, the Hausman test was performed. Random effects in our model are rejected by a Hausman test (Hausman, 1978), which checks the comparability of the two sets of estimates (fixed effects and random effects). For this reason, we only present the fixed-effects model findings from the panel models for quantile regression and linear regression. The results of fixed effects regression are attached in appendix. On the other hand, model in initial-differences moment conditions is combined with model in levels moment conditions to provide the system GMM estimator for dynamic panel data models.

System Generalized Method of Moment (GMM) for SDI and ISDI

To choose between random or fixed effects regression, the Hausman test was performed. Random effects in our model are rejected by a Hausman test (Hausman, 1978), which checks the comparability of the two sets of estimates (fixed effects and random effects). For this reason, we only present the fixed-effects model findings from the panel models for quantile regression and linear regression. The results of fixed effects regression are attached in appendix. On the other hand, model in initial differences moment conditions is combined with model in levels moment conditions to provide the system GMM estimator for dynamic panel data models. These general estimators are meant to be used in scenarios where there are "small T, large N" panels, which indicate a large number of individuals over a short period of time; non-exogenous independent variables that are correlated with past and possibly current realizations of the error; fixed effects;

and heteroskedasticity and autocorrelation within individuals. For the current study, the combined results for system GMM of SDI and ISDI are shown in Table 4.

Table 4: Estimated Results				
Variables	**GMM for SDI**		**GMM for ISDI**	
	Coefficients	**Std. errors**	**Coefficients**	**Std. errors**
Index value	0.389*** (0.000)	0.193	-0.061* (0.065)	0.027
Precipitation	-0.249* (0.067)	0.134	-0.800*** (0.009)	0.212
Wind speed	1.062** (0.029)	0.478	0.031* (0.077)	0.014
Max temperature	-0.413** (0.029)	0.185	-0.172** (0.037)	0.064
Min temperature	0.219 (0.224)	0.178	-0.037 (0.918)	0.346
Sex ratio	-0.017*** (0.006)	0.006	0.967*** (0.010)	0.260
Household size	0.043** (0.025)	0.019	-0.047*** (0.000)	0.393
Dependency ratio	0.783*** (0.011)	0.302	-0.666*** (0.000)	0.088
ICT	0.171*** (0.000)	0.010	0.105 (0.214)	0.075
Value of assets	0.044*** (0.000)	0.011	-0.017 (0.358)	0.017
Province1	-0.739 (0.167)	0.053	0.154*** (0.001)	0.025
Province2	-0.080** (0.035)	0.037	0.133*** (0.009)	0.034
Province3	-0.598 (0.866)	0.0259	0.059*** (0.019)	0.018
Diagnostics				
No. of obs	525		525	
F-test	0.000		0.007	
AR (2)	0.139		0.603	
Hansen test	0.239		1.000	

Note: * indicates 10% level of significance. ** indicates 5% level of significance. *** indicates 1% level of significance. P values are in parentheses.

According to the results of GMM on the left side of table 4, the probability value of the F-test is 0.000 which is highly significant, indicating that the model is a good fit model. It has been found that the estimated model of SDI does not exhibit bias according to the diagnostic tests. The over-identification test revealed that the model is not over-identified since the research invalidates the Sargan test's null hypothesis. The Hansen test result, which is 52.44 with a probability value of 0.239, indicates that all instruments are valid.

The SDI is a key dependent variable in the model. To get accurate estimates of the impact of independent variables, regression analysis has used lag dependent variables (LDVs). The lag value of SDI reveals that the remaining independent variables in the model appear to be related to an increase in SDI, based on the positive and highly significant coefficient of SDI which is 0.389 and significant at 1% level of significance.

The correlation between precipitation and the SDI is negative (-0.249), implying that heavier precipitation corresponds to a lower index. At the 10% level, the outcome is statistically significant. Heavy rainfall can have a number of negative effects on the natural environment, including agricultural loss, soil erosion, and a higher risk of flooding. Heavy rains can also cause injuries, drownings, and other health problems associated to flooding. Furthermore, because contaminants deposited on land wash into water bodies, precipitation-related runoff can degrade the quality of water (Environmental Protection Agency (EPA), 2021).

The SDI indicates to be positively correlated with wind speed, as shown by the positive and highly significant value of coefficient which is 1.062. High wind speeds are favorable for the production of wind energy. Increased generation of energy can be a benefit for nations that invest considerably in wind power, which will contribute to the environmental aspect of the SDI. In accordance with SDI objectives connected to environmental sustainability, this encourages the transition to renewable and sustainable energy sources according to the IPCC report 2011.

Maximum temperature has a negative and highly significant impact on SDI, showing that greater maximum temperatures are connected with a decline in the SDI. Watts et.al (2018) argued that increases in maximum temperatures have the potential to cause more heatwaves, which subsequently in response to increase the risk of heat-related disorders like dehydration and heatstroke. This may put a burden on healthcare systems and affect life expectancy.

The SDI does not appear to be significantly impacted by the minimum temperature as the results shows that the coefficient of minimum temperature is insignificant. By creating circumstances that are favorable for living and working, comfortable minimum temperatures can increase human productivity. More steady job output and economic growth could result from fewer weather-related disruptions.

The SDI found to be associated with a larger sex ratio, attributed to a bias towards males, which corresponds to a very significant negative coefficient of -0.017. According to various studies, a more balanced sex ratio is related to greater economic output, but imbalances can lead to problems in the labor market and broader social issues, as stated by the UNDP report. 2020.

A higher SDI correlates with larger household sizes, based on a positive and significant coefficient value of 0.043 and significant at 5% level of significance. According to Kelbaugh et.al (2017), larger household sizes may make it easier to use resources more effectively by sharing living areas, appliances, and utilities. This can result in less garbage being produced and less energy being used per person, both of which improve environmental sustainability. The results for household size are not consistent as it is a multifaceted phenomenon. A larger age dependency ratio may be linked to a rise in the SDI, due to the positive and significant value of the coefficient that is 0.783 and significant at 1% level of significance. Borsch-Supan (2013) stated that the productivity of society as a whole is increased by the elder population who opt to work or take part in the economy. This could help alleviate the economic burden imposed on by a growing elderly population and promote sustainable development.

The SDI appears to be positively correlated with increasing levels of information and communication technology, according to the positive and highly significant coefficient value of 0.171. According to the report of the World Bank (2018) ICT promotes financial inclusion and supports economic development by making financial services reachable in remote locations. A larger asset value is correlated with an increase in sustainable development as the variable ownership of assets is positively and significantly associated with sustainable development. Ownership and secure property rights foster investment, entrepreneurship, and the growth of the economy. Assets that are legally owned by people and communities are more likely to be developed and invested in, which increases prosperity and eliminates poverty, stated by De Soto (2000).

The concept of sustainable development is sophisticated and multidimensional, and a multitude of factors can impact the differences that exist between provinces in a nation such as Pakistan. Province 1, province 2, and province 3 refer to Baluchistan, KPK, and Punjab, respectively. The coefficients for the provinces show that, compared to the base province (Sindh), all provinces have less progress towards SDI, but Baluchistan has a more negative impact on SDI, as it has insufficient resources and less developed cities. On the other hand, Punjab is highly populated and contributes more in carbon emissions compared to other provinces. In terms of sustainable development, areas with superior natural resource management techniques can have an edge. This covers conservation of the environment, agricultural methods, and water management. It gets difficult for regions dealing with security issues to draw in investments, develop the economy, and deliver basic necessities. Because of its geopolitical setting, KPK has had security issues, which may have an effect on its growth.

The model is statistically significant, as indicated by the highly significant probability value of 0.007 for the F-test, which is based on the GMM results on the right side of Table 4. It has been determined that the diagnostic tests show no bias in the calculated ISDI model. As a result of the research invalidating the null hypothesis of the Sargan test, the over-identification test indicated that the model is not overidentifying. All instruments are valid in the model, according to the Hansen test result, which is 1 with a probability value of 0.000.

The dependent variable in the model is the Inequality-adjusted SDI. The findings show that the ISDI is negatively impacted by climate change. Although it does not reach statistical significance at standard levels, the inequality-adjusted sustainable development tends to decline. In order to interpret a negative ISDI, there is need to understand that, even in the case of positive indicators such as wealth, education, and life expectancy, the unequal distribution of these advantages results in an overall unfavorable evaluation of sustainable development. It suggests that not all groups of people are gaining the full benefits of the fundamental gains in living standards, health care, and education.

With a p-value of 0.009, precipitation exhibits a coefficient of -0.800. Lower levels of inequality-adjusted sustainable development have been associated with increased precipitation, according to the highly statistically significant negative coefficient. The findings suggest that areas suffering more precipitation may find it more difficult to achieve sustainable development, particularly as a result of problems like infrastructure damage, flooding, or disruptions to agriculture. Lobell et.al (2008) explained that Agriculture may suffer from both too much and too little precipitation. While droughts can lower yields and risk food security and farmers' livelihoods, floods have the potential to completely destroy crops. Both situations can harm the sustainable development of a country. An excessive amount of precipitation can result in flooding, which damages buildings, roads, and bridges and hinders economic activity as well as sustainable development, argued by Kundzewicz et al. (2004).

According to the positive wind speed coefficient, the ISDI rises by about 0.031 percent for a one-unit increase in wind speed. At the 10% significance level, the outcome is statistically significant. The significance of wind energy in the shift to a sustainable energy future is highlighted by a study conducted in 2015 by Jacobson et al. Wind turbine efficiency and output are directly affected by wind speed and are crucial for producing electricity from wind power. Elevated wind velocities usually lead to enhanced energy generation from wind farms, hence expanding the capacity for renewable energy. Thus, this promotes sustainable development by reducing the need for fossil fuels as well as decreasing greenhouse gas emissions.

The coefficient for the maximum temperature is -0.172. At the 5% level of significance, the negative coefficient is statistically significant and indicates that lower levels of inequality-adjusted sustainable development are linked to higher maximum temperatures. This may refer to difficulties involving resource and infrastructural strain, effects on agriculture, and heat stress. High temperatures have a wide range of effects on sustainable development, impacting social, environmental, and economic sides. High temperatures have the potential to cause variations in precipitation patterns, heat waves, and droughts, which can impact food supply and crop yields. This may lead to a shortage of food, an increase in food costs, and more economic strain on farming communities, as reported by IPCC (2014). Rising temperatures can put a burden on infrastructure and energy systems, increasing the need for cooling, raising the possibility of heat-related damage, and increasing the expense of adaptation.

According to the minimum temperature's negative coefficient, the ISDI decreases by 0.037 percent for a one-unit increase in minimum temperature. The outcome isn't statistically significant, though. According to Stern (2007), minimum temperatures have the ability to alter employment possibilities and economic activities. Industries such as construction, tourism, and agriculture could have difficulties that result in disparities in the economy.

The ISDI increases by 0.967 percent for a one-unit increase in the sex ratio, according to the positive and significant coefficient for sex ratio. Hudson et.al (2002) argued that social stability is frequently associated with a balanced sex ratio because excessive imbalances can cause social discontent and intensify competition for resources. Social cohesiveness is often higher in societies with more equal sex ratios.

The ISDI decreases by 0.047% for a one-unit increase in household size at 1% level of significance, according to the negative coefficient for household size. But the outcome is not significant. Larger homes frequently use more resources, which raises the need for energy, water, and other necessities. This increased consumption may hamper long-term sustainability by causing environmental deterioration and the depletion of natural resources (Ehrlich et.al 1971).

According to the dependency ratio's negative coefficient, the ISDI decreases by 0.666 percent for each additional unit in the dependency ratio. Dependency ratios can exacerbate overall inequality when they interact with other socioeconomic factors. High dependency ratios have the potential to negatively affect social services like healthcare and education, which could result in insufficient support for the dependent population.

According to the positive coefficient for ICT, the ISDI rises by 0.105% for one unit increase in ICT. However, the outcome lacks statistical significance. It's important to understand that the use of ICTs may make already-existing disparities worse, such the digital gap caused by access to technology (Warschauer 2004).

The ISDI decreases by 0.017 units for every unit that the ownership of assets grows, according to the negative coefficient of ownership of assets. The outcome shows that the value of assets has a considerable influence on the ISDI but it is not statistically significant. The income levels of people and households are frequently determined by who owns productive assets, such as enterprises, capital, and land. A society's income disparity may be worsened by a concentration of wealth in the hands of a small number of people. Different population groups may not have equal access to resources and opportunities as a result of income disparities.

When focusing on the provinces and comparing them with the base province (Sindh), each has a positive coefficient that is highly statistically significant, indicating that living in these provinces is linked to higher levels of inequality-adjusted sustainable development. The results indicate that due to its low human development indicators, Baluchistan, the largest province in terms of area, suffers from difficulties such as low rates of literacy and inadequate healthcare services. Despite the abundance of natural resources in the province, there is still a development gap due to problems with resource distribution and utilization. Sindh is well-known for its commercial center, Karachi, the biggest city in Pakistan and a significant contributor to the GDP of the nation. But Sindh also has to deal with issues like high rates of poverty, particularly in rural regions, and unequal access to healthcare and education. The most populated province, Punjab, is frequently regarded as having the most advanced infrastructure and economy. Compared to other provinces, it has a comparatively higher literacy rate and better access to healthcare and educational resources. Despite these facts, Punjab is also facing pollution and inter-regional inequalities.

The effects of climate change on sustainable development by estimating the overall results using OLS regression, system GMM, and quantile regression. The period span of the study is from 2004 to 2019. The study's hypothesis that climate change has a negative impact on sustainable development is supported by the findings. The results indicate that precipitation and maximum temperatures, and sex ratio have a significant impact on sustainable development, while wind speed shows inconsistency in the results. However, the minimum temperature shows a positive and significant impact on sustainable development. On the other hand, the dependency ratio and household size vary in estimation, as both variables have a complex and multifaceted relationship with sustainable development. ICT has both negative and positive impacts on sustainable development, but on average the overall impact of ICT is positive and significant. Ownership of assets also has a positive and significant impact on sustainable development. On the provincial level, the results indicate that KPK has negative and significant results for SDI, while Baluchistan and Punjab have inconsistent results compared to Sindh (base province).

The techniques mentioned above are also used to examine the impact of ISDI; the results revealed that there is a negative and significant relationship between precipitation, maximum temperature, dependency ratio, and ISDI. The overall impact of minimum temperature and ICT is positive but insignificant on ISDI. On the other hand, some variables (wind speed, ownership of assets, household size) showed inconsistency and variability towards ISDI. The sex ratio results showed a significant and negative influence in the first two analyses, but the quantile regression results were consistent for the first three quantiles, with positive and significant outcomes. The results also revealed that Balochistan has high inequality in terms of ISDI as it has positive and significant outcomes compared to Sindh. While comparing Punjab and KPK with Sindh, they have variation in their results. Although the results of fixed effects and GMM differ, the results of the focused regression, which is GMM in our study, are more credible.

5. Conclusion

The climate of our planet has been mostly stable for the past 10,000 years, while in present times it is extremely unstable and periodically experiences sudden changes due to natural processes. In recent decades, there has been an increase in weather and climatic extremes that cause natural disasters. Such occurrences, along with socioeconomic shifts that heighten their exposure and raise the possibility of maladaptation, are hindering the economic and social growth of developing nations (Hay 2010).

The idea of sustainable development is essential to the modern era. It is a means of interpreting the entire world as well as a strategy for resolving international issues. The Sustainable Development Goals (SDGs) will direct worldwide economic diplomacy in subsequent decades. In order to meet existing needs without risking future generations' ability to meet their own, the World Business Council for Sustainable Development (WBCSD) defines sustainable development as "forms of progress." The task of addressing current demands is of the utmost importance, given the magnitude of poverty in the entire world today. However, we have to consider the future and make every effort to make sure that the things we do for our expanding population now are not compromising the needs of our descendants in terms of the environment, society, or human welfare.

The current study examined the impact of climate change on sustainable development at the district level. The micro-level policy implications of climate change are not being addressed. This study used temperature, precipitation, and wind speed as three different climate change indicators to measure the effects of the changing climate in different ways. Additionally, it investigated whether or not the changing environment has a negative impact on the SDI and ISDI of various districts in Pakistan. The study investigated the impact of climate change on sustainable development through quantile regression, system GMM, and OLS regression overall result estimation. The study's time frame was from 2004 to 2019. The results of the study provide credibility to the concept that climate change has an adverse impact on sustainable development. The findings demonstrate that wind speed exhibits inconsistent results, but precipitation, maximum temperatures, and the sex ratio have a negative and significant impact on sustainable development. However, there is a noticeable and favorable influence of the minimum temperature on sustainable growth. However, because of their intricate and complex relationships to sustainable development, the estimation of the dependency ratio and household size varies. ICT has an impact on sustainable development that is both beneficial and bad, but overall, it has a substantial and positive impact. Asset ownership has a major and beneficial influence on sustainable development as well. At the provincial level, the findings show that KPK has significant and negative SDI values, whereas Punjab and Baluchistan have inconsistent results when compared to Sindh.

In the case of ISDI, precipitation, maximum temperature, dependency, and ISDI have a negative and significant association. The minimum temperature and ICT has a positive overall effect on ISDI. However, in relation to ISDI, a few factors (wind speed, ownership of assets, and household size) showed variability and inconsistency. In the first two investigations, the sex ratio results indicated an insignificant and negative influence; however, the quantile regression results were consistent with the other regression results but showed sex ratio to be positively significant. In addition, the data showed that Baluchistan has more ISDI inequality than Sindh due to its favorable and significant findings for ISDI. When contrasting the results of Sindh with Punjab and KPK, there are differences.

Policy Recommendations

To tackle the effects of climate change on sustainable development, a comprehensive and integrated strategy is necessary. These are some suggested policies that would mitigate the consequences of climate change while advocating sustainable development.

Pakistan should introduce safe modes of energy to reduce the impact of greenhouse gas emissions.

Districts should adopt policies that are suitable for them according to their area like districts having more severe temperature should use solar energy. Due to the abundance of sunlight, solar energy can be very useful in hot climates. Problems with water scarcity can be made worse by high temperatures. Water supply in these places can be ensured by putting water conservation measures in place, such as effective irrigation structures, collecting rainwater for irrigation, and reducing water waste.

Stormwater runoff can be managed, floods can be decreased, and city adaptability to severe precipitation events can be increased through the use of green infrastructure solutions including rain gardens, permeable pavement, and green roofs for the districts facing heavy rainfall.

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