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A Comprehensive Analysis of The Dynamic Space-Time Impacts of Climate Change on Poverty in Egypt

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A COMPREHENSIVE ANALYSIS OF THE DYNAMIC SPACE-TIME IMPACTS OF CLIMATE CHANGE ON POVERTY IN EGYPT

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Abstract

This paper explores the relationship between climate conditions and poverty in Egypt at a sub-national level, considering various factors and estimation techniques. Using a functional data analysis (FDA), this paper explores the long-term effects of summer temperatures, winter temperatures, and precipitation on poverty across Egypt. The FDA results highlight the evolving relationship between temperature changes and poverty, emphasizing the heightened influence of summer temperatures on poverty rates over the past three decades. Additionally, the contrast in temperature dynamics before and after 1985 emerges as a significant predictor. A geographically weighted regression model reveals distinct patterns in different areas. The paper contributes to understanding the climate-poverty nexus and emphasizes the need for tailored strategies at the local level for climate resilience and poverty alleviation.

Keywords: Climate change, Egypt, Functional data analysis, Geographically weighted regression, Poverty.
JEL Classifications: C21, I30, Q51.

ملخص

تستكشف هذه الورقة العلاقة بين الظروف المناخية والفقر في مصر على المستوى دون الوطني، مع مراعاة مختلف العوامل وتقنيات التقدير. باستخدام تحليل البيانات الوظيفية. تحلل هذه الورقة الآثار طويلة المدى لدرجات حرارة الصيف ودرجات حرارة الشتاء وهطول الأمطار على الفقر في جميع أنحاء مصر. تسلط نتائج إدارة الغذاء والدواء الأمريكية الضوء على العلاقة المتطورة بين تغيرات درجات الحرارة والفقر، مع التأكيد على التأثير المتزايد لدرجات الحرارة في الصيف على معدلات الفقر على مدى العقود الثلاثة الماضية. بالإضافة إلى ذلك، يظهر التباين في ديناميكيات درجة الحرارة قبل وبعد عام 1985 كمؤشر مهم. يكشف نموذج الانحدار المرجح جغرافيًا عن أنماط مميزة في مناطق مختلفة. وتسهم الورقة في فهم الصلة بين المناخ والفقر وتشدد على الحاجة إلى استراتيجيات مصممة خصيصا على الصعيد المحلي من أجل القدرة على التكيف مع تغير المناخ والتخفيف من حدة الفقر.

1. Introduction and Background

In response to the escalating threats of climate change, a substantial body of research has emerged across various sectors such as agriculture (Birkman et al., 2022; Hallegate and Rozenberg, 2017; Jacoby et al., 2011; Kandeel, 2019; Schlenker and Roberts, 2009; Tull, 2020), human health (Deschênes and Greenstone, 2011; Elayouty et al., 2022), and labor productivity (Abou-Ali et al., 2022; Skoufias et al., 2011; Somanathan et al., 2021). The central concern revolves around the potential impact of climate change on economic growth and its subsequent implications on poverty, highlighting the importance of understanding the dynamics of this relationship (Diffenbaugh and Burke, 2019; Hsiang et al., 2019; Lankes et al., 2022; Newell et al., 2021). The relationship between poverty and climate change is bidirectional; poor households with limited resources face heightened vulnerability to climate-related shocks, while poverty can drive activities that intensify climate change (Birkman et al., 2022; Lankes et al., 2022). The factors governing this relationship include social, economic, and institutional elements, with consistency in the poverty-climate link highlighted by Awad and Warsame (2022).

A warming climate is expected to affect the availability of and accessibility to necessities, such as food, freshwater, and energy (Dagnachew and Hof, 2022). Individuals with lower economic means are likely to encounter greater challenges in dealing with and recovering from extreme climate events, disrupters, and crises such as epidemics, economic downturns, health hazards, and natural disasters. The impacts of climate change on household welfare demonstrate intricate variations, particularly evident within a single country and exacerbated in regions experiencing pre-existing poverty and health inequalities. This scenario is pertinent in countries like Egypt. Effectively addressing the interrelationship between climate change and poverty requires comprehensive strategies that acknowledge their inherent linkages. These approaches must be adapted to the specific socioeconomic, environmental, and health dynamics of each region. Only through such tailored approaches can equitable progress be achieved, thereby steering countries toward a sustainable future. Recognizing the unique challenges faced by vulnerable populations is crucial for developing interventions that not only mitigate climate-related risks but also uplift communities economically and enhance their resilience in the face of multifaceted adversities.

Global warming and adverse climate conditions exacerbate poverty through various channels, affecting land, labor, and food prices, leading to health crises and economic losses (Assunção and Chein Feres, 2009; Jacoby et al., 2011; Skoufias et al., 2011). Climate-related shocks, like floods and droughts, disproportionately impact poor households, prompting coping strategies that perpetuate poverty (Hallegate and Rozenberg, 2017). Agriculture, a key sector for poor households, is highly vulnerable to climate-related shocks, threatening local production, employment, and food security. Climate change contributes to intergenerational poverty transmission, impacting women's economic opportunities and children's development. Moreover, policies such as carbon pricing, designed to mitigate climate change, may raise energy and food costs, potentially increasing poverty. The redistributive nature of such policies influences their impact on poverty rates (Kandeel, 2019; Tull, 2020; Lankes et al., 2022). In addition, the impacts of climate change are not evenly distributed across and within countries, in the sense that the less affluent groups are possibly the ones to bear the most harmful consequences (Dang et al., 2023). Geographical disparities exist within a country, with rural communities dependent on agriculture being more susceptible to poverty due to climate-related shocks. Ignoring subnational variations could easily mask the dynamic effects of climatic conditions on poverty. Therefore, studying the effects of climate change on poverty using data at the district level within a country can reveal the true effects of climate change on economic growth and help in understanding the roots of poverty in the context of environmental challenges (Azzarri and Signorelli, 2020; Garafa et al., 2021; Hansen et al., 2019; Soergel et al., 2021). In sum, a holistic approach considering these complex linkages is essential for addressing poverty and climate change challenges, ensuring sustainable and equitable progress (Lankes et al., 2022; Awad and Warsame, 2022).

The scarcity of empirical evidence on the global warming and poverty nexus can be attributed to the challenges of obtaining accurate measures (Dang et al., 2023). The significant variations in poverty within and across countries underscore the importance of a more refined analysis that considers subnational variations (Damania et al., 2020; Kalkuhl and Wenz, 2020; Dang et al., 2023). This paper seeks to fill this gap by examining the correlation between climate conditions and poverty across Egypt. Despite contributing minimally to global CO_2 emissions (less than 0.6 percent), Egypt is severely impacted by extreme weather due to its geographical location and arid climate. The vulnerability of the Nile River to heatwaves and rising sea levels compounds challenges for a population with a 30 percent poverty rate, ranking Egypt as the 87^{th} most vulnerable nation to climate change (World Bank, 2021). The consequences of heatwaves extend across various sectors of the Egyptian economy, from water scarcity and biodiversity disturbance to tourism fluctuations and public health challenges.

The objective of this paper is to understand the long-term effects of climate change on poverty rates in Egypt and to disentangle the complex spatial dynamics between climate conditions and poverty across diverse geographical regions and household characteristics in Egypt. The paper contributes fresh insights to the body of existing literature on the distributional effects of climate change, with a specific emphasis on understanding the impacts of both hot and cold temperature deviations on poverty across Egypt. This research also seeks to understand and quantify geographical inequalities in the distribution of poverty, pinpointing the areas most susceptible to environmental hazards.

Beyond its scholarly merit, this paper carries profound policy implications. By identifying the specific geographic areas most vulnerable to climate change, policymakers can strategically channel resources and interventions in the fight against poverty. This research serves as a bridge between theoretical insights and actionable policy, enabling Egypt to make informed decisions that safeguard its marginalized citizens from the far-reaching impacts of climate change. The paper is organized as follows. Section 2 describes the data and section 3 explains the analytical framework employed for studying the cumulative effects of temperature changes on poverty as well as the geographic disparities in the impacts of climate conditions on poverty across Egypt. Section 4 presents and discusses the data analysis and modeling results. Finally, section 5 concludes with the main findings and policy recommendations and highlights important directions for further research.

2. Data

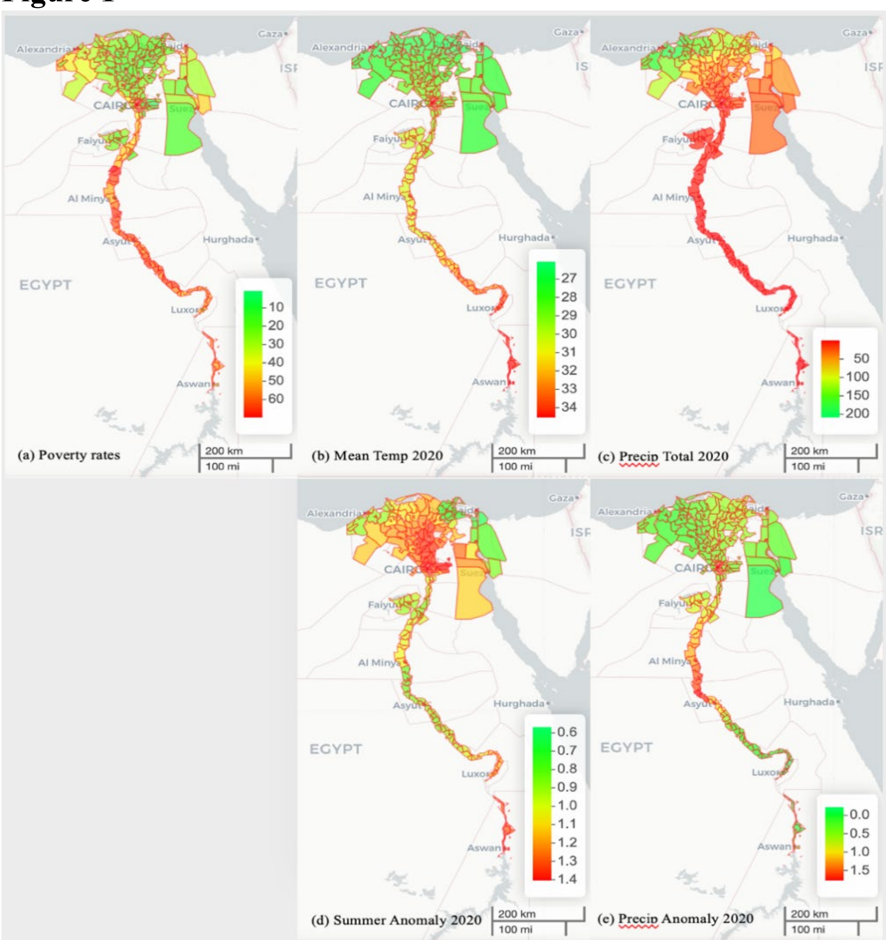
The paper offers insights into the dynamic implications of temperature fluctuations spanning the period 1950 to 2020 on poverty in Egypt. To achieve this objective, the paper relies on aggregated estimates of poverty as well as socioeconomic characteristics at the second administrative (*Kism/Shyakha*) level across Egypt. These estimates are calculated from the 2019/20 Egypt Household Expenditure, Income, and Consumption Survey (HEICS). The Egypt HEICS presents a large database for socioeconomic and demographic differentials and provides a large amount of data for measuring the living standards of households and individuals, hence estimating poverty rates at various administrative levels. The data used in the study cover 365 subnational units across Egypt referred to as Kism in urban areas and Shyakha in rural areas. The poverty rate at a subnational unit is measured based on the national poverty line, set at EGP 736 per capita per month.

The socioeconomic and demographic variables employed in this study include the percentage of individuals with secondary education or higher, the percentage of households residing in owned property, the percentage of female-headed households, the average household size, and an aggregated index reflecting the average percentage of household ownership of assets such as cars, fridges, microwaves, water heaters, air conditioners, motorbikes, bicycles, and washing machines at the second administrative level of the country (Kism/Shyakha).

To assess the relationship between climate change and poverty in Egypt, the above HEICS data are matched with monthly averages of $0.5^o \times 0.5^o$ climate-gridded satellite time series data obtained from the Climate Research Unit (CRU) at the University of East Anglia. These climate data cover the period 1950-2020 and are aggregated at the Kism/Shyakha level. The climate data are used to calculate the average annual maximum temperatures and annual total precipitation at each subnational unit. The average annual maximum temperatures during the summer and winter months are also calculated. To evaluate the effects of changes in climate on poverty, the maximum temperature anomalies in winter and summer as well as the precipitation anomaly for the year prior to the HEICS are computed as standardized deviations from the historical averages over the period 1950-2020.

All the demographic and socioeconomic variables exhibit large disparities across the country (see Table 1). The percentage of individuals with secondary education or higher across Egypt ranges between 0 and 66 percent, while the percentage of households living in owned flats extends between 21 and 99.7 percent and the percentage of female-headed households varies from 0 to 90.42 percent. Panel (a) in Figure 1 provides a geographical map of poverty across Egypt, which displays a substantial variation of poverty, ranging from below 20 percent in Greater Cairo and the Delta region to above 60 percent in Upper Egypt. Simultaneously, Panels (b) and (c) in Figure 1 depict spatial variation in temperatures across Egypt, with average temperatures in 2020 ranging from 26 to 35 degree Celsius. In general, temperatures increase toward the south of Egypt, whereas precipitation levels increase in the Delta and coastal regions (see Panel (c) in Figure 1). Panel (d) also depicts the distribution of the maximum summer temperature anomalies relative to the average maximum summer temperatures in the period 1950-2020, highlighting higher deviations in Greater Cairo and east of the Delta in addition to Aswan in the south of Egypt. As for precipitation anomalies, panel (e) shows that they reach their maximum in Al-Minya and Asyut. Conversely, there was not much variation between the different districts with respect to the winter temperature anomalies (not displayed here).

Figure 1



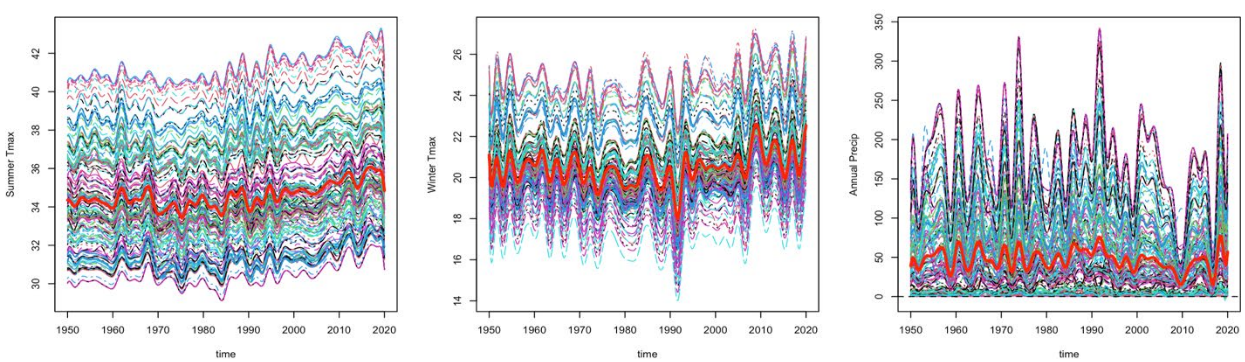
Map of poverty in percent (a) and climate variables - average maximum temperature (b), total precipitation (b), summer maximum temperature anomaly Z-score (d) and precipitation anomaly Z-score (e) in 2020 across Egypt districts (second administrative level – Kism/Shyakha), excluding the frontier governorates.

Figure 2 illustrates a slight increasing trend in the average temperature in Egypt over the study period that is more pronounced in the summer months relative to the winter months. This sheds light on the importance of examining the cumulative effects of changes in climate on economic growth and poverty at the subnational level of Egypt. The wide-ranging subnational variations in both poverty and climate conditions emphasize the importance of studying the relationship between global warming and poverty, recognizing that these dynamics may vary across different regions.

Table 1. Summary Statistics of the Response and Explanatory Variables

Variable	Min.	Q1	Median	Q3	Max.	Mean	St. Dev
Poverty Rate	1.03	16.71	22.45	34.68	69.43	27.29	15.52
Average Max Summer Temp	30.73	33.01	35.13	36.84	41.68	34.89	2.57
Average Max Winter Temp	18.78	20.00	20.67	21.14	24.45	20.78	1.12
Total Precipitation	0.39	10.80	31.40	83	2017.1	56.57	56.73
% Secondary Education	0	30.94	37.60	41.89	66.10	34.60	12.13
% Living in Owned Flat	20.82	72.08	90.02	96.80	99.71	82.18	18.39
% Possession	13.99	21.97	27.53	34.74	62.15	29.19	9.39
Average Household Size	2.05	3.79	4.01	4.23	4.86	3.99	0.38
% Female-Headed Households	0	12.08	14.86	18.75	90.42	19.93	18.39

Figure 2



Temporal trends of summer temperature (left), winter temperature (middle), and precipitation (right) over the period 1950-2020 across the different districts (Kism/Shyakha) in Egypt along with the overall mean in red.

3. Methodology

As mentioned above, this paper pursues two main goals. The first goal is to understand the cumulative temporal impacts of global warming over the period 1950-2020 on poverty in Egypt. This analysis is implemented while controlling for several socioeconomic and demographic variables known to influence poverty. The second goal involves investigating whether and how the impacts of climate conditions on poverty may vary spatially within Egypt, discerning differences from one region to another.

To analyze the cumulative impacts of climate and the pattern of temperature variation through the period 1950 to 2020 on current poverty rates in Egypt, we employ a functional linear model. In this model, poverty serves as the scalar response while climate profiles act as functional covariates. The method draws upon a Functional Data Analysis (FDA), a field of statistics that has received considerable attention in the last two decades. This approach proves to be a particularly useful technique for the analysis of data collected as multiple time series, providing a sensible alternative to a panel data analysis. In the FDA, each time series is considered as one realization of a continuous smooth function. Hence, the fundamental idea of the FDA is to express discrete observations arising from a time series in the form of a smooth function. This representation encapsulates the entire measured function as a single observation, enabling a more nuanced understanding of the complex dynamics between climate variables and poverty over the specified period.

In this paper, a fundamental unit of interest is the entire smooth function of the climate variable (summer temperature – winter temperature - precipitation) over the period 1950-2020. Afterward, the first step in the analysis involves constructing smooth functions or climate profiles from the discrete annual climate measurements obtained for each Kism/Shyakha using a basis function expansion. This leads to 365 continuous functions for each of the summer mean annual temperature, winter annual mean temperature, and total annual precipitation, which can be illustrated by the following linear combination:

$$x_{ji}(t) = \sum_{k=1}^{K_j} c_{jik}\, \phi_{jk}(t) = \boldsymbol{c}_{ji}^{\top} \boldsymbol{\phi}_j(t), \quad j = 1,2,3 \; and \; i = 1,2, \dots, 365$$

where $\boldsymbol{\phi}_j(t) = \left(\phi_{j1}, \dots, \phi_{jK_j}\right)^{\top}$ is the vector of K_j basis functions used to approximate the profiles of the j-th climate variable and $\boldsymbol{c}_{ji} = \left(c_{ji1}, \dots, c_{jiK_j}\right)^{\top}$ is the corresponding vector of basis coefficients to be estimated for the i-th subnational unit (Kism or Shyakha) and j-th climate variable using the least squares method. The functions/profiles of a certain variable share the same basis functions, but different variables may have different basis functions based on the nature and the characteristics of the variable. There are multiple choices for the basis functions, including polynomials, splines, Fourier series, and wavelets (Ramsay and Silverman, 2005). In this paper, cubic B-splines, known for their flexibility and computational efficiency, are employed to approximate the profiles of the three climate variables. The basis system for each variable is allowed to have different degrees of freedom and complexities.

After obtaining the climate profiles for each Kism or Shyakha, a functional linear model with a scalar response and a mix of scalar and functional covariates are fitted. This model regresses the poverty rates on the climate profiles, alongside other socioeconomic and demographic explanatory variables. The formulation of the model is as follows:

$$Y_i = \beta_0 + \int_t \beta_1(t) STemp_i(t)\, dt + \int_t \beta_2(t) WTemp_i(t) dt + \int_t \beta_3(t) Precip_i(t) dt + \sum_j \gamma_j z_{ji} + \epsilon_i, \ \ \epsilon_i \sim N(0, \sigma^2)$$

where Y_i is the poverty rate in area i, $STemp_i(t), WTemp_i(t)$ and $Precip_i(t)$ are the smooth summer temperature, winter temperature, and precipitation profiles over the period 1950-2020 for area i and z_{ji} are the scalar covariates, including the socioeconomic and demographic characteristics for area i, and ϵ_i is the random error. In the above model, $\beta_1(t), \beta_2(t)$ and $\beta_3(t)$ are the functional regression coefficients measuring the cumulative effects of the climate variables' profiles on poverty and γ_j are the coefficients of the scalar explanatory variables in the model. The functional regression coefficients are expressed in terms of a basis functions expansion and estimated using the penalized least squares method. More details on the estimation of this model can be found in Ramsay and Silverman (2005).

To achieve the second aim of the paper, the geographical differences in poverty are modeled to allow the relationship between poverty rates and various climatological and socioeconomic variables at the Kism/Shyakha level to flexibly vary from one area to another. The climatological variables include the average maximum temperature and total precipitation in the year prior to the HEICS, in addition to the maximum summer and winter temperatures and total precipitation anomalies in the same year relative to the historical averages. This is performed using the Geographically Weighted Linear Regression (GWR) model, introduced by Brunsdon et al. (1996), given by:

$$Y_i = \alpha_0(u_i, v_i) + \sum_{k=1}^{p} \alpha_k(u_i, v_i)\, x_{ik} + \varepsilon_i,$$

where (u_i, v_i) are the geographical coordinates of location i within the region $D \in R^2$, which can possibly be the coordinates of the district's centroid, and ε_i is the error term with mean zero and common variance σ^2. α_k's are the local regression coefficients at location i, estimated using the geographically weighted least squares method on a pointwise basis using kernel-based methods. That is, the $(p+1) \times 1$ coefficients vector $\widehat{\boldsymbol{\alpha}}(u_i, v_i)$ at the point of geographic coordinates (u_i, v_i) is estimated by minimizing a weighted sum of squares resulting in the following estimate:

$$\widehat{\boldsymbol{\alpha}}(u_i, v_i) = \left(\boldsymbol{X}^T \mathbf{W}_{(u_i, v_i)} \mathbf{X}\right)^{-1} \mathbf{X}^T \mathbf{W}_{(u_i, v_i)} \mathbf{Y},$$

where $\boldsymbol{X}$ is the $n \times (p+1)$ design matrix and $\mathbf{W}_{(u_i, v_i)}$ is an $n \times n$ weighting diagonal matrix that contains the weight of each observation $j = 1, \ldots, n$ according to its distance to the regression point

i with coordinates (u_i, v_i). The observations closer to point i are assumed to have more influence over the estimated parameters at location i than more remote observations; hence, the weights' values in the matrix decrease as the distance to the point i increases. The decrease in the weight of each observation with the distance to the regression point i is determined according to a weighting kernel function $K(.)$. The Gaussian Kernel, which is among the most popular continuous weighting kernels and the one employed in this analysis, is defined as follows:

$$K(d_{ij}) = \exp\left(-\frac{{d_{ij}}^2}{2h^2}\right),$$

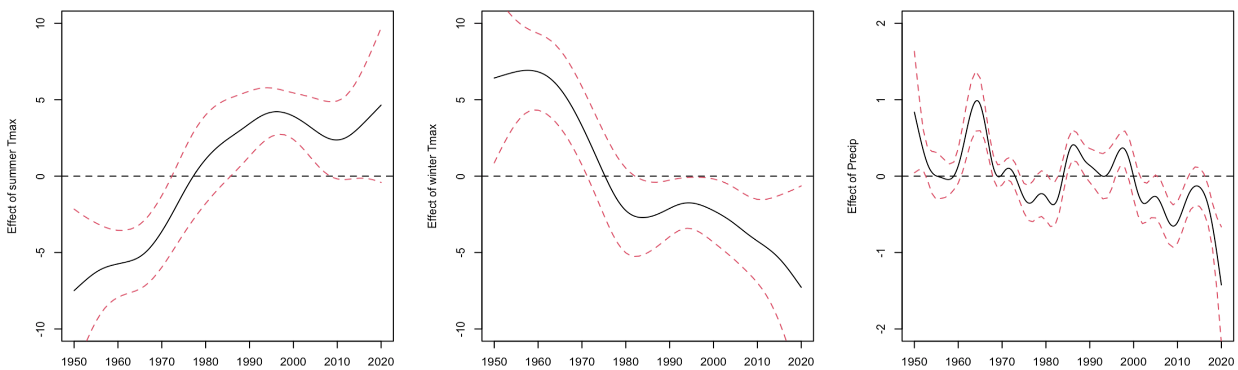
where d_{ij} is the distance between the locations of observations i and j, and h is the kernel bandwidth. It defines the extent beyond which the weight is minimal and is chosen based on goodness of fit criterion such as the Akaike Information Criterion (AIC). This bandwidth is a trade-off between minimizing both bias and uncertainty in the estimated coefficients. A large bandwidth implies a global model and the local coefficient estimates will be biased but have low uncertainty, while a small bandwidth implies a more local model and hence the estimates will have large variance but low bias (Mitchell, 2012).

4. Results and Discussion

The analysis started by examining the long-term effects of climate change on poverty across Egypt by fitting the above functional linear model with the Kism/Shyakha average poverty rate as the response variable. Figure 3 visually represents the estimated average cumulative impacts of summer temperatures, winter temperatures, and precipitation on poverty in Egypt. The results indicate that summer temperatures are positively associated with poverty rates and that the effect of summer temperatures on poverty has been increasing significantly over the past three decades. In contrast, colder temperatures exhibit a negative effect on poverty. These results are consistent with those of Dang et al. (2023) based on subnational data from 134 countries. The estimated effects of temperature indicate that an increase in the average summer temperature by one degree Celsius increases the percentage of poverty by an average of four percent across Egypt. Conversely, a one-degree Celsius decrease in winter temperature in Egypt is associated with a four percent and six percent average increase in the poverty rate, a trend that has been rising in recent years. It is also evident that the contrast in both the average summer and winter temperatures before and after the 1980s is a significant predictor of poverty rates across Egypt. This observation aligns with many studies indicating that the temperature in Egypt has gradually increased over the years, with a significant rise since the 1970s, which is consistent with global warming and climate change (Hasanean and Abdel Basset, 2006; Dadamouny and Schnittler, 2016; Hussein and Mohamed, 2016). Regarding precipitation, its effect on poverty is primarily negative but minimal compared to temperature effects. This result is expected, as Egypt generally experiences low levels of rainfall.

The remaining model results for the other scalar variables and their significance are displayed in Table 2. The results indicate that the poverty rate within a certain district is significantly inversely related to the average percentage of individuals possessing assets such as cars, fridges, microwaves, air conditioners, motorbikes, and washing machines in the same area. Another notable observation that aligns with expectations is the significant rise in the average percentage of poverty as family size increases. The other socioeconomic variables in the model are negatively correlated with poverty but do not exhibit significant relationships in the presence of other variables in the model. Overall, the fitted model represents a good fit to the data as shown in Figure 4, which depicts the observed versus the fitted values. This comprehensive examination of scalar variables offers valuable insights into the socioeconomic factors influencing poverty dynamics in Egypt. The nuanced relationships revealed in the model contribute to a more holistic understanding of the multidimensional determinants of poverty.

Figure 3



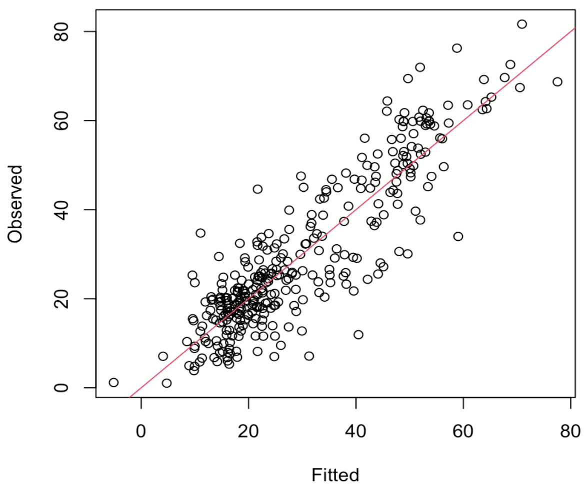
The estimated regression coefficients reflect the effects of summer temperatures, winter temperatures, and precipitation on poverty rates across Egypt, along with 95 percent confidence intervals.

Table 2. Estimated Regression Coefficients of the Scalar Covariates in the Functional Linear Model

Variable	Coefficient Estimate	Standard Error	Lower Limit of 95% C.I.	Upper Limit of 95% C.I.
Intercept	0.3947	0.5417	-0.6887	1.4781
% Secondary Education	-0.0016	0.0009	-0.0035	0.0003
% Living in Owned Flat	-0.0006	0.0006	-0.0017	0.0005
% Possession	-0.0043	0.001	-0.0063	-0.0023
Average Household Size	0.2115	0.0246	0.1623	0.2607
% Female-Headed Households	-0.0005	0.0007	-0.0019	0.0008

The model outlined above assumes constant relationships between the response and covariates across various districts in Egypt. This assumption might not hold true due to the wide-ranging disparities in environmental conditions and substantial heterogeneities in socioeconomic variables across different regions in Egypt. Recognizing this, a geographically weighted regression (GWR) approach is adopted. This approach accounts for variations in response-covariate relationships across different geographical areas, enabling a more accurate representation of the complex dynamics underlying poverty's relationship with climate, changes in climate, and socioeconomic factors.

Figure 4. A Scatter Plot of the Observed Poverty Rates vs the Corresponding Fitted Values from the Functional Linear Model

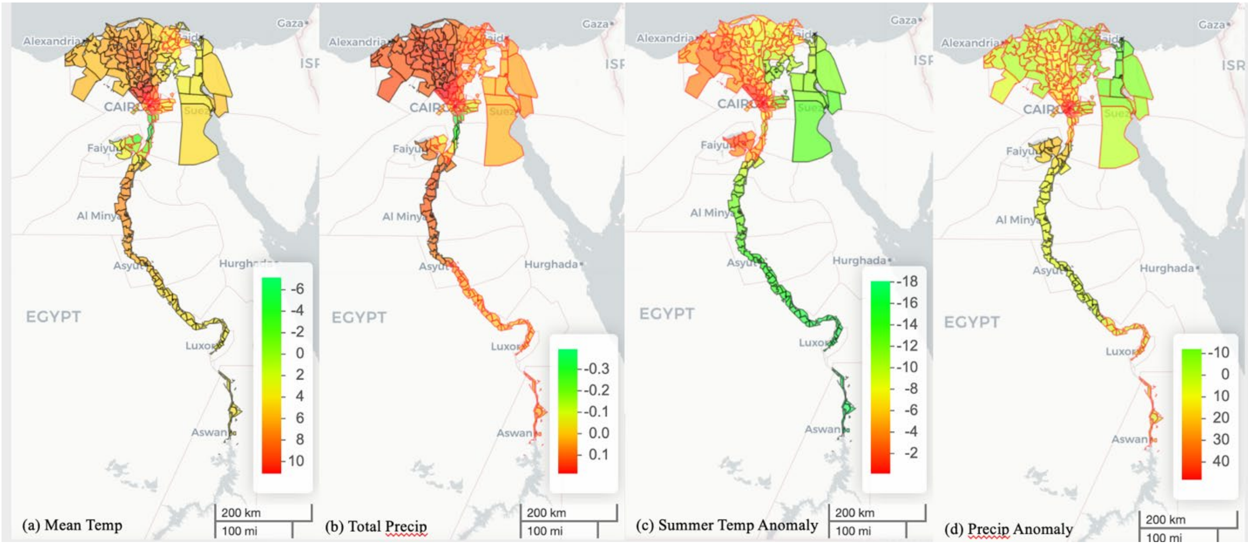


Before fitting the designated GWR model, the bandwidth defining the scale of variability of the different relationships in the model is selected based on AIC, as explained in the methodology section. The bandwidth is defined adaptively based on the neighborhood size, which is set at 45 districts. This indicates that the relationships in the model operate at a regional/moderate scale. The fitted GWR model effectively accounts for approximately 72 percent, on average, of the variability in the percentage of poverty across Egypt. It is important to note that the model was applied after excluding the frontier governorates, ensuring a focused and accurate analysis. Visual representations of the coefficients' geographic distributions are presented in Figures 5 and 6. These figures serve a descriptive purpose and should guide further studies to better interpret these local relationships.

Panel (a) in Figure 5 illustrates significant disparities in the concurrent connection between the mean temperature level and poverty across Egypt. Upper Egypt—namely Asyut, Al-Minya, and Benisuef—experiences hotter and drier climates compared to Greater Cairo, contributing to immediate and pronounced impacts on livelihoods, especially for vulnerable populations. Agricultural activities, prevalent in Upper Egypt, are sensitive to temperature fluctuations, further affecting income and poverty rates. On the other hand, Greater Cairo benefits from enhanced infrastructure, services, and economic diversification as a major urban hub, providing a buffer against temperature shocks (Jacoby et al., 2011; Angelson and Dokken, 2018). Panel (b) in Figure 5 highlights the limited variability in the concurrent relationship between precipitation and poverty across Egypt. This can be attributed to the low rainfall across Egypt. The relationship between precipitation and poverty is significantly positive, mainly in the western part of the Delta and in Fayoum, Benisuef, and Al-Minya, but significantly negative in the southern parts of Greater Cairo.

Regarding climate anomalies relative to historical data, deviations in winter temperatures do not appear to be a significant predictor of poverty and are therefore removed from the model. The summer temperature anomaly is negatively associated with poverty across Egypt. Panel (c) in Figure 5 indicates a significant negative association between the summer temperature anomaly and the poverty rates in the Northeastern regions, such as Al-Sharkya and Suez, as well as throughout Upper Egypt. This association becomes more evident in the southern areas of the country, implying that the economic status of households living in Southern Egypt may be more resilient to climate change compared to other areas. This resilience might be attributed to adaptive strategies such as the implementation of more effective cooling systems or changes in agricultural practices, which mitigate the adverse effects of temperature fluctuations (Alvar-Beltrán et al., 2021; Benitez-Alfonso et al., 2023; Grigorieva, 2023). As for the precipitation anomaly, it is significantly positively associated with poverty along the middle areas of the River Nile mainstream in Egypt. This region experienced higher-than-average precipitation levels in the year prior to HEICS, leading to potential flooding, waterlogging, and, subsequently, crop failures. Such events can exacerbate poverty by damaging infrastructure, reducing agricultural yields, and increasing the vulnerability of affected communities. This positive association highlights the importance of improving flood management, developing resilient agricultural practices, and offering insurance to small farmers to mitigate the impact of precipitation level and poverty (Berhanu et al., 2024; FAO, 2023; Tabe-Ojong et al., 2020).

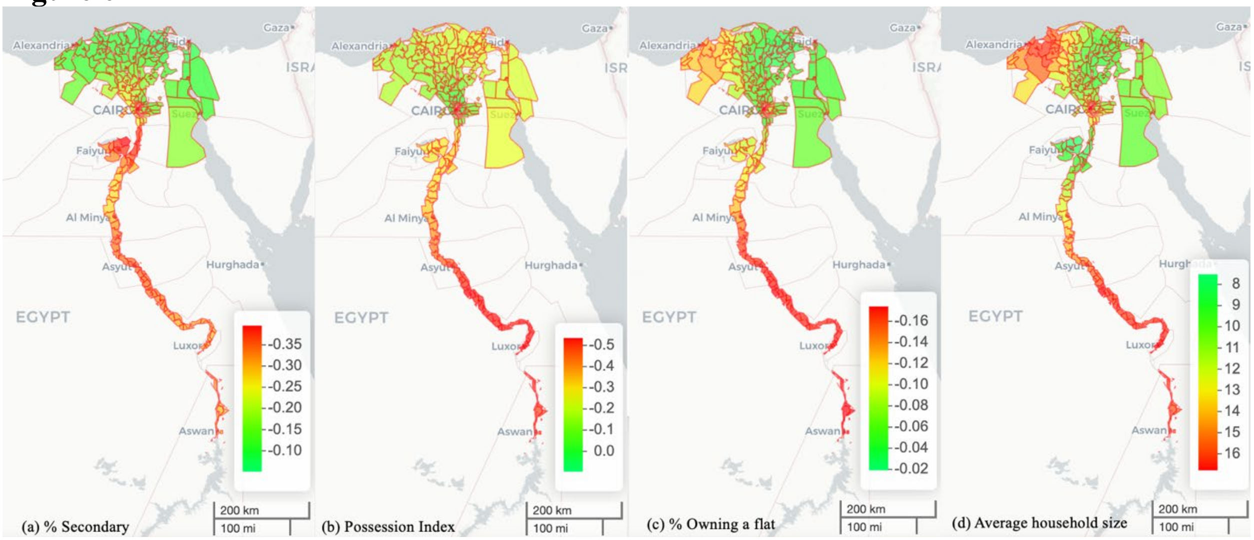
Figure 5



Map of the coefficient estimates of climate variables - average maximum temperature (a) total precipitation (b), summer maximum temperature anomaly (c) and Precipitation anomaly in year 2020- obtained from the GWR fitted to the data of Egypt, excluding the boundary governorates. Black boundaries indicate the significance of the coefficient in the district.

Figure 6 illustrates the negative correlation between socioeconomic variables and poverty, with variations across regions. Greater Cairo and the Delta region exhibit a subdued influence, potentially due to higher urbanization levels moderating the relationship between socioeconomic factors and poverty. As for the average household size in Panel (d) of Figure 6, a positive relationship with poverty holds true across the country, intensifying in Upper Egypt. This can be attributed to a combination of socioeconomic, demographic, and geographic factors unique to the region, such as traditional family structures, limited access to job opportunities, and larger rural and agricultural communities. These interrelated factors underscore the complex relationship between socioeconomic dynamics and regional disparities in poverty across Egypt. Understanding these nuances is crucial for targeted and effective policy interventions aimed at reducing poverty and enhancing resilience in the face of environmental challenges. It is essential to recognize that the above factors are interrelated, potentially reinforcing each other, thereby culminating in the observed pattern where the influence of socioeconomic factors on the percentage of poverty becomes more pronounced in Upper Egypt. For instance, educational attainment emerges as a pivotal determinant of income and poverty levels, as shown in Panel (a) of Figure 6. In regions with lower educational levels, families may possess limited awareness of family planning methods and the potential advantages of smaller family sizes. This can result in larger household sizes, which, in turn, can strain available resources and contribute to higher poverty percentages. Such interrelations can be masked if the geographic location is not accounted for.

Figure 6



Map of the coefficient estimates of socioeconomic and demographic variables – percentage of individuals with secondary education (a), average possession index (b), percentage of households owning a flat total (c), and the average household size (d) - obtained from the GWR fitted to the data of Egypt, excluding the boundary governorates.

5. Conclusions

Egypt, facing the challenges of extreme weather due to its geographical location and arid climate, stands at the crossroads of climate vulnerability and poverty. The Nile River, vital to the nation, is susceptible to heatwaves and rising sea levels, compounding challenges for a growing population with a significant poverty rate. In the face of escalating climate change threats, understanding its complex relationship with poverty is essential. This paper contributes to the existing literature by exploring the relationship between climate conditions and poverty at a subnational level in Egypt. The analysis examines the long-term effects of climate change on poverty across Egypt using data spanning from 1950 to 2020. The study employs a functional linear model and incorporates an FDA to assess the impact of climate variables and climate change on poverty rates at the Kism/Shyakha level. The analysis also investigates spatial variations, recognizing the diverse socioeconomic and environmental dynamics across different regions in Egypt.

Key findings indicate that rising temperatures are positively associated with poverty rates, with a notable increase in the last three decades. Conversely, colder temperatures exhibit a negative impact on poverty. Precipitation, while having a mainly negative effect on poverty, proves minimal relative to temperature variations. The relationships between climate variables and poverty are further highlighted through a geographically weighted regression (GWR) approach, capturing the nuances across different geographical areas and allowing for the visualization of the variability within a country. By identifying the specific geographic areas most vulnerable to climate change, policymakers can strategically channel resources and interventions to combat poverty effectively. Yet, the analysis here is based on district-level aggregates of sociodemographic variables, which can be overly simplistic for some areas.

It is important to develop and implement localized climate mitigation strategies that consider the distinct climate conditions in various regions. Including measures to address rising summer temperatures is essential. Policymakers must consider unique challenges in different regions and across time to design timely interventions that enhance adaptability and reduce vulnerabilities to address the climate change-poverty nexus. To mitigate the impact of rising summer temperatures and variable precipitation on agricultural yields, particularly in Upper Egypt, developing climate-resilient agriculture practices is crucial. Promoting the adoption of heat-resistant crop varieties and drought-resistant farming techniques can enhance agriculture productivity. Finally, providing training and resources for farmers on modern irrigation methods along with encouraging agroforestry practices to enhance soil moisture retention and provide shade for crops can significantly improve resilience to climate change.

Improving cooling infrastructure is essential to reduce the positive association between high summer temperatures and poverty rates by enhancing access to cooling technologies. Given the negative coefficient associating between asset ownership, housing status, and poverty rates, expanding the availability and affordability of cooling appliances (such as fans and air conditioners) in poverty-stricken areas and promoting passive cooling techniques in building designs can help mitigate the adverse effects of high temperatures on vulnerable populations. Promoting socioeconomic development is vital to address the socioeconomic determinants of poverty, such as improving education attainment and reducing household size. Increasing access to education, particularly in Upper Egypt, can reduce poverty rates. Implementing family planning programs to raise awareness of the benefits of smaller family sizes and providing access to contraceptives can help manage household sizes.

Bridging theoretical insights with actionable policy recommendations, this study guides policymakers in formulating targeted and effective strategies and to make informed decisions that safeguard Egypt's marginalized citizens from the far-reaching impacts of climate change. In conclusion, this paper underscores the critical need for a holistic approach that considers the complex spatio-temporal linkages between climate conditions and poverty. By doing so, Egypt can pave the way for sustainable and equitable progress, ensuring the well-being of its population and enhancing resilience in the context of environmental challenges.

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